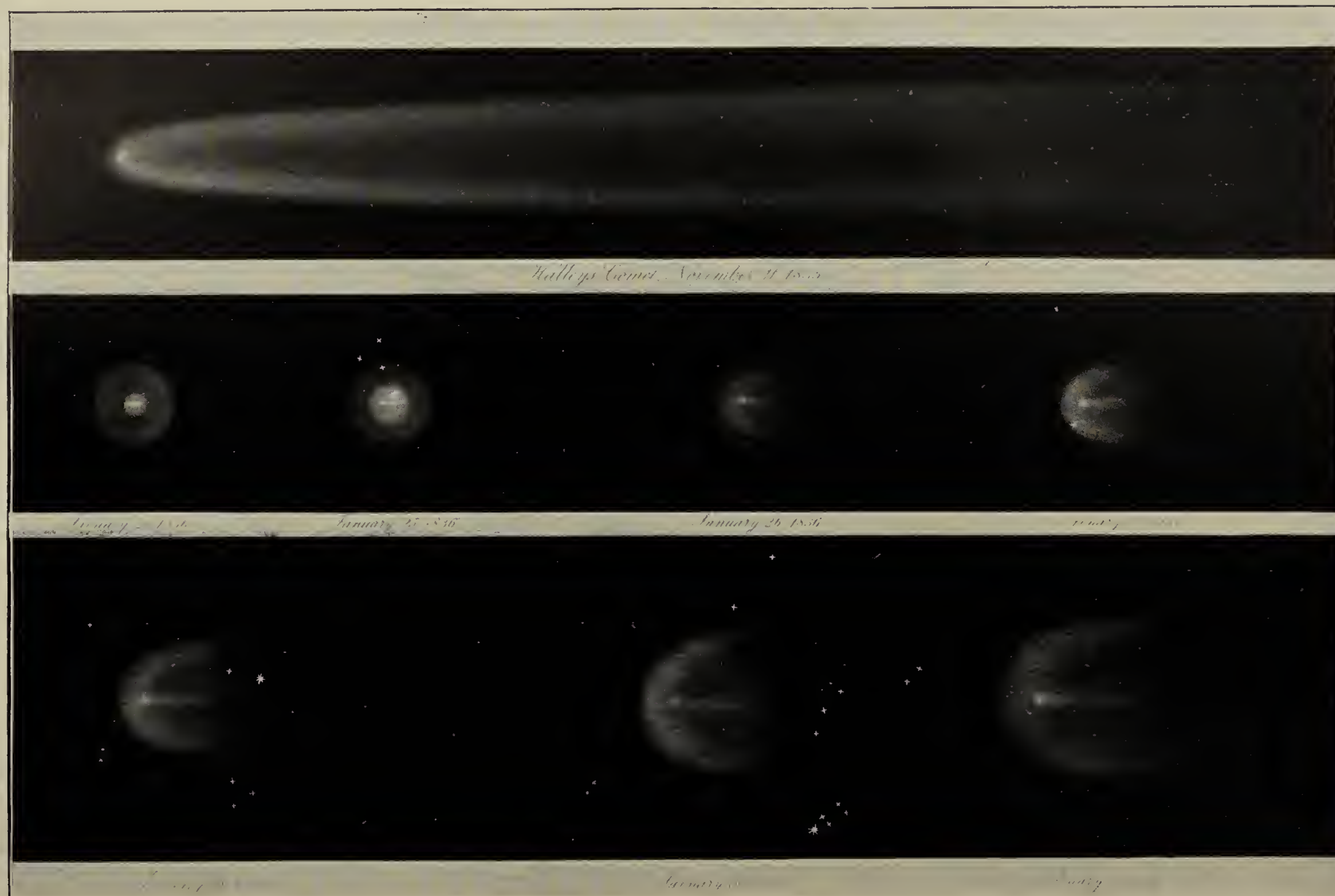

HALLEY'S COMET, 1835–36.

(*Drawn by C. P. Smyth.*)

Frontispiece.

THE STORY OF THE COMETS

SIMPLY TOLD FOR GENERAL READERS.

BY

GEORGE F. CHAMBERS, F.R.A.S.

OF THE INNER TEMPLE, BARRISTER-AT-LAW.

AUTHOR OF

"A HANDBOOK OF ASTRONOMY," "A CONVERSATIONAL ENGLISH-FRENCH-GERMAN DICTIONARY," "THE TOURIST'S POCKET-BOOK," AND OTHER WORKS.

DISCOVERY FIELD OF BROOKS'S COMET OF 1895 (iii.).

"If there be aught throughout the pearly deep
Of Heav'n's unfathomable ocean wide,
That doth affect man's soul
With wonder and delight
Beyond the rest of vast Creation's wealth,
'Tis Thou, Mysterious Star."
(*Anon.*, March, 1843.)

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1909

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HENRY FROWDE, M.A.
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PREFACE.

This volume scarcely needs a preface, for the title-page tells its aim, and implies the motives which have inspired it. It may, however, be confessed that the great public interest which seems to have sprung up in connection with the expected return this year or next of "Halley's Comet" had something to do with the non-publication of the book last year and its non-postponement till next year.

I have modelled it on the Comet chapters of my well-known *Handbook of Astronomy*, but every line of those chapters has been rewritten, altered, corrected, or expanded, and new chapters added, to embody the different conditions of our knowledge in 1909 contrasted with the circumstances of nearly a quarter of a century ago.

I have to thank various friends for advice and assistance in making the book more useful than it would have been without such advice and assistance; in particular, Mr. A. C. D. Crommelin, B.A., F.R.A.S., of the Royal Observatory, Greenwich, and Mr. W. E. Rolston, F.R.A.S., of the Solar Physics Observatory, South Kensington; and Mr. D. Smart, F.R.A.S.; whilst as regards the illustrations I owe thanks to the Council of the Royal Astronomical Society; to

the Proprietors of *Punch*; and to various private friends, English and American, amongst whom I must mention Professor H. H. Turner of Oxford, Mr. Percy Morris, F.R.A.S., of Sutton, Surrey, and Professor E. E. Barnard and Mr. Morehouse in America. I am also under great obligations to Mr. R. C. Slater, M.A., of St. Peter's College, Cambridge: and the Rev. R. D. Pierpoint of St. John's College, Cambridge, for reading the Proof-sheets, and making various suggestions.

G. F. C.

LETHEN GRANGE,
SYDENHAM:
July, 1909.

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26, line 27. *Add*:—"It was suggested by Bessel that some of the changes which he noticed to have been undergone by Halley's Comet in 1835–6 were the result of a rotation on its axis in a period of about 5 days, and a similar suggestion was made with respect to Morehouse's Comet of 1908 (iii). Both comets also suffered the loss, in a certain sense, of their tails for a time."

32. It is not quite certain to whom the pictures forming Plates VII. and VIII. should be ascribed, as some of the American photographs reached me without authors' names.

163, line 2. *Add*:—"Another term used in connection with the elliptic orbits of comets is 'the Epoch of Osculation', which is the time for which the perturbed orbit has been calculated. To get the time of perihelion passage from it take the Mean Anomaly, M (or 360°—M, if M is near 360°); reduce it to seconds and then divide it by the mean daily motion in seconds (μ); the quotient is the interval in days between the Epoch and the time of perihelion. Where M is an angle of a few degrees it means that perihelion precedes the Epoch, but where M is near 360° it means that perihelion follows the Epoch."

213, line 2. *Add*:—"But Pope in speaking of a 'Red Comet' when he describes Minerva's rapid descent from Heaven has tampered with the original Greek, for Homer says not a word about any comet, but evidently alludes to a falling star, or meteor of some kind." (Pope, *Iliad*, book iv, line 101; iv, 75, in the Greek.)

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THE STORY OF THE COMETS.

CHAPTER I.

GENERAL REMARKS.

Popular appreciation of Comets and Eclipses and shooting stars.—Comets always objects of popular interest and sometimes of alarm.—Quotation from a writer of the 17th century.—Physical appearance of an ordinary Comet.—Comets without Tails more numerous than Comets with Tails.—General description of a Comet.—The Nucleus.—The Coma.—The Tail.—Small Comets usually circular in form or nearly so.—Path of a Comet.—Great diversity in the size and brilliancy of Comets.—Comets usually diminish in brilliancy at each return.—Halley's Comet, a case in point.—But this opinion has been questioned.—Holetschek's Inquiries.—Actual Dimensions of Comets.—The Colour of Comets.

QUITE irrespective of the remarkable growth of a taste for Astronomy which has marked the last quarter of a century, alike in Great Britain, Greater Britain, and North America, to say nothing of the Continent of Europe, there can be no doubt that comets have, and always have had, a great fascination for that student of science newly named "the man in the street". And next in order of interest certainly come Eclipses, Solar and Lunar, and Fire-balls and "Shooting Stars"; but these do not concern us now. It is not difficult to see why all these phenomena should be attractive to the popular mind: they are all sights which can be seen, and in a measure be studied, without professional teaching, and without much (or any) instrumental assistance.

[a] From the Greek κομήτης, the "long-haired one". A woman's head, with long dishevelled tresses streaming behind her, is often a not inapt representation of a comet with a head and tail.

In bygone times, before the invention of telescopes, it was only of course the larger comets which were or could be recorded; and as these frequently appeared with great suddenness in the nocturnal sky, usually in the first instance not far from the Sun, either after sunset or before sunrise, and often had attached to them tails of great size which were sometimes very bright, comets were well calculated in the earlier ages of the world to attract the attention of all and to excite the fear of many. It is the general testimony of History during many hundreds of years, one might even say during fully 2000 years, that comets were always considered to be peculiarly "ominous of the wrath of Heaven and as harbingers of wars and famines, of the dethronement of Monarchs and the dissolution of Empires". It is quite within the limits of truth to say that ideas such as these have not yet died out. One quotation of 17th-century origin will sufficiently summarize the opinions of many writers and thinkers. A poet of the epoch just named wrote thus:—

"A Blazing Star,
Threatens the World with Famin, Plague and War;
To Princes, death; to Kingdoms many crosses;
To all Estates, ineuitable Losses;
To Herd-men, Rot; To Ploughmen, haplesse Seasons;
To Saylors, storms; to Cities, ciuil Treasons." [b]

Some further quotations of an analogous character are reserved for a subsequent chapter which deals with comets in history and poetry.[c]

However little attention might have been paid by the Ancients to the ordinary displays of natural phenomena, certain it is that Comets and Total Eclipses of the Sun were not easily forgotten or lightly ignored; hence it is that the aspects of many remarkable comets seen in olden times have been handed down to us, often in language of circumstantial minuteness, and still more often in language of grotesque extravagance. The Chinese hold the palm under this head of literary style.

[b] Du Bartas, *His Diuine Weekes and Workes*, trans. J. Sylvester, 1621, p. 33.
[c] See Chap. XIV (*post*).

The physical difference between different comets is a matter very little appreciated or understood by people in general. With such, every thought is concentrated on the comet's tail, if it has one; or if it has not a tail, then the verdict is "no comet". Yet the facts of the case are that the comets with tails are, and always have been, considerably outnumbered by the comets without tails. An explanation of the popular view is to be found in the fact that the tailed comets are very frequently visible to the naked eye, whilst the tailless comets may be said to be never so visible.

An ordinary comet when first discovered by means of a telescope either consists of, or sooner or later developes, three parts. In the latter case the developement takes place some-

Fig. 5.

TELESCOPIC COMET WITHOUT A NUCLEUS.

Fig. 6.

TELESCOPIC COMET WITH A NUCLEUS.

what in the following manner: the telescope reveals a faintly luminous speck; its size increases gradually, and after some little time a *nucleus* appears. This word indicates that a portion of the comet is more condensed in its light than the rest. Both the size and the brilliancy of the object progressively increase; the cloud-like mass around the nucleus (called the *coma* [d]), becomes less symmetrical, and this loss of symmetry, when it occurs, betokens the early developement of a *tail*. Nucleus and coma taken together are generally spoken of as the *head* of the comet. When a tail has become manifest it will be found to be brighter near the head than at the tip, and often brighter on one side than on the other.

[d] Latin for "hair".

"Tip" as applied to the tail of a comet is generally little more than a figure of speech, because it is, as a rule, impossible to say what is the tip, that is, to say where the tail comes to an end. Occasionally the tail increases to a length, it may be, of 10 or 20 degrees of arc or more. In the case of comets of great size and brilliancy this tail sometimes spreads across a large portion of the heavens; sometimes there are more tails than one. An ordinary tail presents the appearance of a stream of milky-white light which is always fainter and usually broader the further from the head that one examines it. Occasionally the broadening of the tail towards its extremity becomes a very marked feature.

The nucleus of a small comet is generally circular, as indeed is the whole comet, but a nucleus is sometimes oval, and, in very rare cases, may present a radiated appearance. The nucleus, if visible to the naked eye (the comet itself being a small one), generally looks like, and may easily be mistaken for a star or a planet, the coma not being visible until a telescope is brought to bear on the comet. But in a telescope such a comet will show as a point of light surrounded by a fog of light. Sometimes, of course, the foggy appearance may reveal itself even to the naked eye if the comet as a whole is sufficiently luminous. Arago remarked that the nucleus is generally eccentrically placed in the head, lying towards the margin nearest the Sun. I do not, however, think that this can be considered an established law applicable to the majority of the small comets; and under any circumstances it would seem to betoken the forthcoming appearance of something of the nature of a tail. Sometimes a comet will have 2 or more nuclei or bright centres of light, but *one* is the normal number.

The newly found comet approaches the Sun in a curvilinear path which frequently differs but little from a straight line. It generally crosses that part of the heavens in which the Sun is situated so near the Sun as to be lost in its rays, but it emerges again on the other side frequently with increased brilliancy and increased length of tail. The phenomena of disappearance are then not unlike those which marked the

original appearance, but in the reverse order. To this it may be added that a comet discovered in the Northern Hemisphere usually passes into the Southern Hemisphere after it has made its nearest approach to the Sun, and disappears in that hemisphere. Conversely, a comet discovered in the Southern Hemisphere generally comes North, and disappears in the Northern Hemisphere, but exceptions to this rule are not uncommon.

In size and brilliancy comets exhibit great diversity. It sometimes, but not very often, happens that one appears which is so bright as to be visible when the Sun has not yet sunk below the horizon; but the majority are invisible to the naked eye, and need either a little, or a great deal of, optical assistance. All these latter are "telescopic comets". The appearance of the same comet at different periods of its visibility varies so much that we can never certainly identify a given comet with any other by any mere physical peculiarity of size, shape, or brightness. Identification only becomes possible when its "elements" have been calculated and compared with those of some other comet previously observed. It is now known that "the same comet may, at successive returns to our system, sometimes appear tailed, and sometimes without a tail, according to its position with respect to the Earth and the Sun; and there is reason to believe that comets in general, for some unknown cause, decrease in splendour in each successive revolution".[e] Halley's Comet, which we are all expecting in 1910 or sooner, has been thought to have diminished in brilliancy during the many centuries that have elapsed since it was first recognized, judging by a comparison of the descriptions given of it; but doubts have been cast on this supposition by Holetschek, who concludes that for a thousand years from 837 A.D. to 1835 its magnitude has remained fairly constant, between the 3rd and 4th star magnitudes; whilst between 1456 and 1835 there was no great variation in the length of its tail.

Holetschek has carried out some investigations as to the magnitude and brilliancy of comets and their tails from the

[e] Smyth, *Cycle*, vol. i, p. 235.

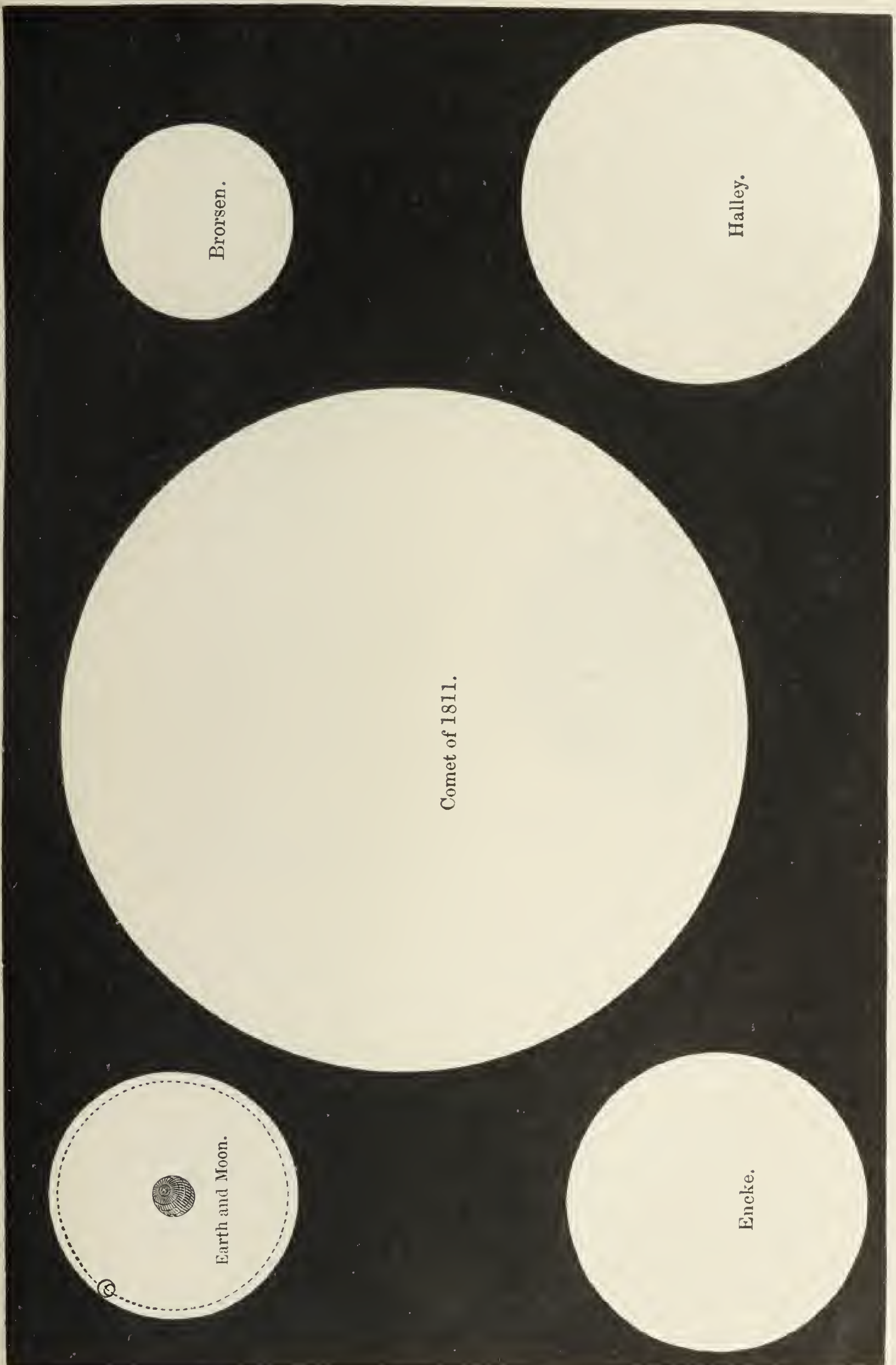
earliest times till 1760 which deserve mention here. His object was to arrange in order of magnitude those comets whose orbits have been computed, in much the same way that stars are classified in orders of brightness. In addition, he has attempted to derive the true length of the tail from the records of apparent length, and to examine to what extent the developement of tails depends upon the magnitude of comets and their perihelion distances. Holetschek endeavoured, and with some success, to apply mathematical formulæ to the question of the comparative brilliancy of different comets. His chief conclusions are that some 70 comets lend themselves to a fairly satisfactory determination of magnitude when reduced to the common standard of the Earth's distance from the Sun taken as Unity; and that to about 50 a numerical value can be assigned to the length of their tails. The magnitudes (taken in star magnitudes) range from —1 (the great Comet of 1744) to $9\frac{1}{2}$ [f]; but the greater number fall between the magnitudes 4 and 6. So far as regards the tails it would not be safe to draw any more precise conclusion than, that the tail is greater the greater the magnitude, and the closer the approach to the Sun. When the magnitude of a comet (reckoned in star magnitudes) is about the 6th or less, then, as a rule, no tail is developed that can be seen with the naked eye; except under specially advantageous circumstances, as when the comet comes near the Earth. When the magnitude is as great as the 4th, almost all comets when near perihelion have tails visible without optical aid. But when the perihelion distance is large the tail developement is very slight.[g]

Plate II represents the comparative diameters of the heads of the well-known comets which are named, as they were measured on particular occasions, compared with the size of the Moon's orbit round the Earth. The woodcut is drawn to scale, but it must not be inferred that the dimensions indicated are in any sense permanent, or very trustworthy.

[f] The ambiguous figure —1 as applied to indicate the magnitude of a star means, speaking roughly, a doubly-bright 1st magnitude star, *e. g.* Sirius and a few others.

[g] *Ast. Nach.*, vol. cxl, no. 3359, June 15, 1896 : summarized in *Nature*, vol. liii, p. 93. Nov. 28, 1895.

Fig. 7. *Plate* II.



COMPARATIVE SIZES OF THE EARTH, THE MOON'S ORBIT AND CERTAIN COMETS, NAMED.

The dimensions may be taken as typical of those of many other comets.

Few things are more remarkable to witness, and more paradoxical to explain, than the changes of bulk which the head of a comet generally undergoes in approaching to, or receding from, the Sun. One might expect, reasoning from terrestrial analogy, that as a comet approaches the Sun the increased heat to which it is submitted would expand its head, whereas the effect observed is the contrary; it grows smaller as it grows hotter. And when receding from the Sun the observed changes are of a converse character; the comet's head seems to expand as it gets farther away and grows cooler. No satisfactory explanation of this anomaly has been given unless it is permissible to accept Sir J. Herschel's idea that the change of bulk is due to some part of the cometary matter remote from the nucleus being evaporated, as it were, under the influence of the Sun's heat, just as a morning mist is evaporated and disappears as the Sun rises in the heavens and its radiant heat becomes more potent.

Fig. 8.

THE COMET OF 1847 (i.), VISIBLE AT NOON ON MARCH 30. (*Hind.*)

History informs us that some comets have shone with such splendour as to have been distinctly seen in the day-time. The comets of B.C. 43, A.D. 575 (?), 1106, 1402 (i), 1402 (ii.), 1472, 1532, 1577, 1618 (ii.), 1744, 1843 (i.), 1847 (i.), 1853 (iii.), 1861 (ii.), 1882 (i.), are the principal ones which have been thus observed. Perhaps we might assume that about 4 or 5 comets are so visible in every century. The Comet of 1853 (iii.) was seen on June 10 at Olmütz only 12° distant from the Sun, and again, after perihelion, on Sept. 2, 3, and 4 at *noon*.

What is the colour of a comet? Have comets ever any colour? From my own observations, extending over many years (and I suppose I have telescopically examined more

comets than most people), I should not have hesitated to answer these questions in the negative, and have said that all comets exhibit a more or less silvery-grey hue. On the other hand, however, there is a certain amount of evidence available which conflicts with this statement. Passing over what I cannot but consider the sensational assertions of many ancient and mediæval writers of comets appearing of the colour of blood, or fiery red, and so on, we do find in the writings of modern astronomers sufficient evidence to show that such tinges as "yellowish", or "yellow", or "ruddy", are not unprecedented both as regards nuclei and tails. The Comet of 1769, the great Comet of 1811, the great Comet of 1843, Donati's Comet of 1858, Coggia's Comet of 1874, and Fabry's Comet of 1886 (i.),[h] are cases in point. To this it must be added that in a few rare cases mention is made of "bluish-green" as a tinge which has been noticed. After all said and done, however, I find that in looking into the published accounts of many comets by many observers in different parts of the world, there is a decided preponderance of testimony in favour of "white" or "silvery-grey", or something of that sort, as being the ordinary hue of most comets.

[h] "Ruddy brown" is the expression used in this case. *Month. Not. R.A.S.*, vol. xlvi, p. 436. June 1886.

CHAPTER II.

PHYSICAL DESCRIPTION OF COMETS.

Comets probably self-luminous.—Existence of phases doubtful.—Erratic changes of brilliancy.—Comets with planetary discs.—Transformations undergone by Comets.—Transits across the Sun never recorded.—Flimsy nature of cometary matter.—Breaking up of a Comet into fragments.—The instance of Biela's Comet.—Observations by Liais of the Comet of 1860 (iii.).*—Other instances of Comets breaking up.—Berberich's investigations respecting Comets which may have broken up.—Comets which follow one another in nearly identical orbits.—Do Comets perish by the exhaustion of their materials?—Summary of opinions as to what those materials probably are.*

It was long a question whether comets are self-luminous, shining with some intrinsic light of their own, or whether, as in the case of the planets, they shine with light reflected from the Sun. Whilst it cannot be doubted that they do exhibit independent light of their own, yet it is now generally believed that to a certain extent some of the light which they yield is received by them from the Sun. It cannot, however, be said that astronomers are agreed upon the point; and further evidence from advocates on both sides of the controversy is much to be desired. The spectroscope negatives the idea that comet light is sunlight, whilst the polariscope seems to indicate the presence of reflected light. Like the instruments named, observers of high repute have taken opposite sides. Sir W. Herschel, from his observations of the Comets of 1807 and 1811 (i.), was in favour of the idea that comets were self-luminous,[a] but the observations of Airy and others on Donati's Comet in 1858 point to exactly the opposite conclusion as regards the *tail* of that comet.[b] If we know little about the heads of comets we know still less about their tails, for they are such strange ethereal structures. If the existence of phases in the case of a comet could be certainly known

[a] *Phil. Trans.*, vol. cii, p. 115. 1812.

[b] *Green. Obs.*, 1858, p. 90.

this would furnish an unquestionable proof that the comet exhibiting such phases shone by reflected sunlight. It has been asserted from time to time that such phases have been seen, but the evidence is very far from satisfactory. Delambre mentions that the Records of the Paris Observatory afford undoubted evidence of the existence of phases in the Comet of 1682; but neither Halley nor any other astronomer who observed that comet has left any intimation of phase phenomena having been noticed by them. James Cassini mentions the existence of phases in the celebrated Comet of 1744;[c] on the other hand, Heinsius and De Chéseaux, who paid particular attention to that comet, positively deny having seen anything of the kind. More recently Cacciatore of Palermo expressed a decided conviction that he had seen a crescent in the Comet of 1819. There were 4 comets in that year and apparently the second is the one referred to. Arago sums up by saying that Cacciatore's observations only prove that the nuclei of comets are sometimes very "irregular", by which word I suppose he means that they conform to no regular laws.[d] Sir W. Herschel states that he could see no signs of any phases in the Comet of 1807 although he fully ascertained that a portion of its disc was not illuminated by the Sun at the time of his observation. Pons's Comet of 1812 was found at its return in 1883–4 to be brighter than the theory of its orbit led one to expect; indeed, it underwent during its visible career various ups and downs of brilliancy instead of varying gradually as its distance from the Earth varied. Niesten suggested that this fact was a proof of the comet being endued with some inherent light of its own. This surmise may be applied to Holmes's Comet of 1892, and Morehouse's Comet of 1908, both of which underwent remarkable fluctuations of brilliancy, in accordance apparently with no definite law. As to both these comets more will be said hereafter.

A critical reader might suggest that the foregoing paragraph conveys an uncertain sound, and the complaint would be well-founded. I should therefore like to take leave of the

[c] *Mém. Acad. des Sciences*, 1744, p. 303. [d] *Pop. Ast.*, vol. i, p. 627, Eng. Ed.

subject by quoting from a well-known American writer of great experience his view of the case, to which I think the same criticism applies. Says the late Professor Young:—"There has been much discussion whether these bodies shine by light reflected or intrinsic. The fact that they become less brilliant as they recede from the Sun, and finally disappear while they are in full sight simply on account of faintness and not by becoming too small to be seen, shows that their light is in some way derived from the Sun. The further fact that the light shows traces of polarization also indicates the presence of reflected sunlight. But while the light of a Comet is thus in some way attributable to the Sun's action the spectroscope shows that it does not consist, to any considerable extent, of mere reflected sunlight, like that of the Moon on Planets."[e] The writer adds:—"If a comet shone with its own independent light, like a star or a nebula, then, so long as it continued to show a disc of sensible diameter, the *intrinsic brightness* of this disc would remain unchanged; it would only grow *smaller* as it receded from the earth, not *fainter*." This last remark does not seem sound.

It occasionally happens that a telescopic comet, especially when first discovered, exhibits a round and well-defined disc. History indeed records this as the attribute of several naked-eye comets discovered either before the invention of the telescope or when the telescopes in use were of a very juvenile character. Seneca, speaking of the second comet of 146 B.C., which appeared after the death of Demetrius, King of Syria, says that it was but little inferior to the Sun, being a circle of red fire sparkling with a light so bright as to surmount the obscurity of night. It is to be presumed that he meant that it was but little inferior to the Sun in size. The Comet of 1652, seen by Hevelius, was almost as large as the Moon although not nearly so bright. The Comets of 1665 and 1682 are said to have been as well-defined in their outlines as the Planet Jupiter. It is doubtful whether these statements can be received as literally true: at any rate I am not acquainted

[e] C. A. Young, *General Astronomy*, Ed. of 1898. p. 442.

with any modern observations of large comets in respect of which such precise language is used.

The transformations which comets undergo are so varied and numerous that it is not easy to reduce them to writing in any very orderly fashion. The following is an excellent instance of these transformations. On August 8, 1769, Messier, while exploring the Heavens with a 2-foot telescope, perceived a round nebulous body which turned out to be a comet. On August 13 a tail about 6° long was visible to the naked eye; on Aug. 28 it measured 15°; on September 2 it measured 36°; on the 6th 49°; and on the 10th 60°. The comet then plunged into the Sun's rays and ceased to be visible. On October 8 the perihelion passage took place; on Oct. 24 the comet again became visible but with a tail only 2° long; on November 1 the tail measured 6°, on the 8th it was only $2\frac{1}{2}$° long, on the 30th only $1\frac{1}{2}$°. After that the comet ceased to be visible. Changes of this character may not unfrequently be noticed.

Transits of comets across the Sun no doubt occasionally happen, but there is no clearly authenticated instance known. The German sun-spot observer Pastorff noticed on June 26, 1819 a round dark nebulous spot on the Sun. It had a bright point in its centre. Subsequently when the orbit of the Comet of 1819 (ii.) came to be investigated, Olbers pointed out that the comet must have been projected on the Sun's disc between 5^h and 9^h a.m. Bremen M. T. Pastorff asserted that his "round nebulous spot" was the comet. Olbers, and with him Schumacher, disputed the claim, and the matter seems not free from doubt.[f] The Comet of 1826 (v.) was calculated to cross the Sun on Nov. 18 of that year, but owing to bad weather in Europe only 2 observers, Gambart and Flaugergues, saw the Sun on that day, and neither of them obtained any trace of the comet in transit. The Comet of 1823 is said also to have crossed the Sun but without having been seen.

[f] For some further particulars as to this controversy see Webb's *Celest. Obj.*, 4th Ed., p. 40, where there is also a facsimile of Pastorff's original sketch. See also an important paper by Hind in *Month. Not.*, vol. xxxv, p. 309. May 1876. Hind seems to have thought that there was either error or fraud in Pastorff's narrative.

The unsubstantial and flimsy nature of comets is shown by the numerous recorded instances of comets passing in front of stars without dimming their light, much less obliterating them. Sir J. Herschel once watched Biela's Comet pass in front of a cluster of stars without any obliterating effect being noticed; and observations of this kind have so often been recorded since that it is not worth while to cite instances in detail. There are, however, some observations to the contrary on record. A partial stoppage of light seems suggested by what Sir W. Herschel stated respecting the Comet of 1807. He says that stars seen through the tail lost some of their lustre, and that one near the head was only faintly visible by glimpses.[g] Again, on Sept. 13, 1890, an 11th mag. star is said to have completely disappeared during the passage in front of it of Denning's Comet. It unfortunately happens that we possess no clearly expressed record of the *nucleus* of a comet having been seen to occult a star, and therefore the extent of the solidity which is to be regarded as an attribute of cometary nuclei is at present indeterminate. According to Max Wolf the Comet of 1903 (iii.) seemed to absorb some of the light of stars which it passed over. These citations suggest that the comets in question were more dense than the general run of comets.

A question of great interest which is often raised is, "Do comets ever break up and disperse and disappear?" The question must certainly be answered in the affirmative, but the cases on record are not numerous,[h] and except in a few instances the evidence is not very definite. Seneca mentions on the authority of Ephorus, a Greek author, that the Comet of 371 B. C. separated into two parts which pursued different paths.[i] Seneca seems to distrust the statement which he repeats, but Kepler accepted it after what he himself had

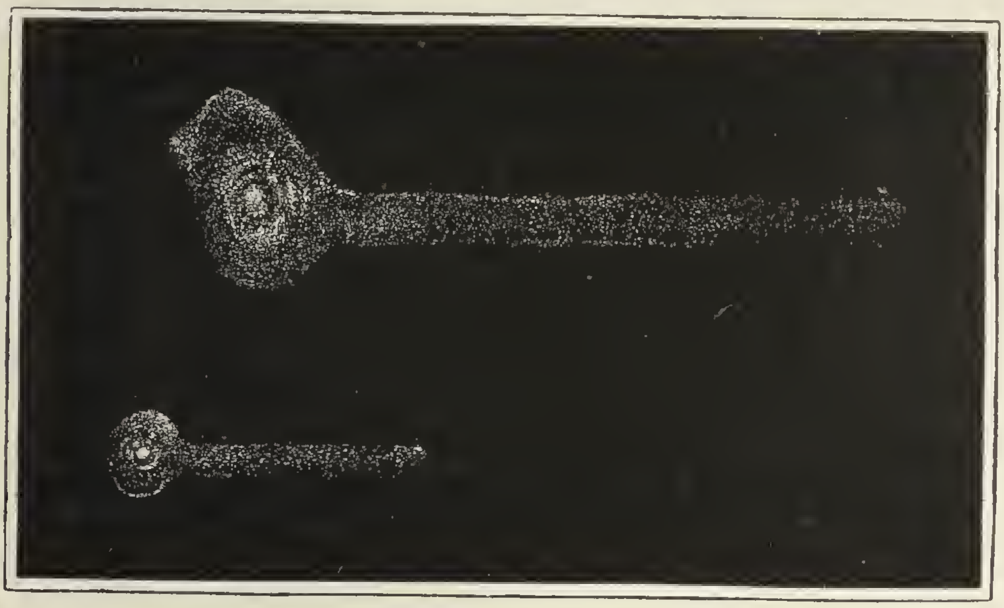
[g] *Phil. Trans.*, vol. xcviii, p. 153. 1808.

[h] Callandreau has formed the conclusion that the limit of distance at which the breaking up of comets by the action of the Sun and Jupiter is possible is not considerable, and that such catastrophes need not be rare.

[i] *Quæst. Nat.*, lib. vii, cap. 16. But he says, however, of the writer he quotes :—"Ephorus vero non est religiosissimæ fidei; sæpe decipitur, sæpe decipit," which strikes a blow at the value of his testimony.

seen in observing the great Comet of 1618. In the case of this comet Cysatus noticed an evident tendency in it to break up. When first seen it was a nebulous object, but some weeks afterwards it appeared to consist of a group of several small nebulosities. But the best authenticated instance of this character is that of Biela's Comet in 1845–6. When first detected, on November 28, it presented the appearance of a faint nebulosity, almost circular, with a slight condensation towards the centre: on December 19 it appeared somewhat elongated, and by the end of the month the comet had actually separated into two distinct nebulosities, which travelled

Fig. 9.



BIELA'S COMET, FEB. 19, 1846. (*O. Struve.*)

together for more than 3 months: the maximum distance between the parts (about 160,000 miles) was attained on March 3, 1846, after which it began to diminish until the comet was lost sight of in April. At its return in 1852 the separation was still maintained, but the interval had increased to 1,270,000 miles. As I shall have a good deal to say about Biela's Comet in a later chapter no more need be said about it here.

Biela's Comet does not stand alone among modern comets as regards its duplicity. A comet seen in February and March, 1860, only by E. Liais, a French observer in Brazil, consisted when discovered of a principal nebulosity accom-

panied at a short distance by a second and fainter nebulosity, which disappeared before the principal nebulosity was lost to view. It is to be regretted that this object remained visible for so short a time as a fortnight, and that our knowledge of it depends on the authority of only one observer.[k] The Comet of 1881 (ii.), according to the testimony of 2 observers, threw off a fragment which became virtually an independent comet, and lasted as such for some days, when all trace of it was lost[l]; but a still more interesting case is that of Brooks's Comet of 1889 (v.) described in some detail in a later chapter.[m]

Another very striking instance is afforded by Swift's Comet of 1899 (i.) which was carefully studied by Bredichin. It was discovered on March 13, 1899, by L. Swift, and passed its perihelion about a month later. Before this it had a stellar nucleus of the 10th mag., a coma 7′ in diameter, and a small tail. After perihelion it became visible to the naked eye and brightened up to the 3rd mag. with a tail several degrees long. On May 7 the nucleus was observed at the Lick Observatory to be double, and the 2 portions gradually separated until on May 21 they were 29′ apart. The fainter portion was followed till June, until it was too faint to be seen. The comet eventually assumed what is known as the "scymitar" form, and showed indications of twisting which suggested the idea of rotation or oscillation about the line drawn from the Sun to the comet. The tail was of type I of the Bredichin types, with the exception of a faint stream which was of type III.[n] There was no difficulty in tracing on photographs the outward and vibratory motion of the material of the tail, and Bredichin says that the extremity of the tail, as seen on May 19, was formed of matter which had left the head 4 days earlier. He does not hesitate to say that the partition of the tail was caused by the disturbing influence of the Sun, and that both nuclei were moving in hyperbolic paths, the smaller nucleus

[k] *Ast. Nach.*, vol. lii, no. 1248. April 14, 1860.

[l] Bone, *Month. Not.*, vol. xlii, p. 105, Jan., 1882; Gould, *Nature*, vol. xxiv, p. 342, Aug. 11, 1881.

[m] See p. 78 (*post*).

[n] These types will be described in a subsequent chapter. See p. 34 (*post*).

pursuing a hyperbola of greater eccentricity than that affected by the larger nucleus. In the memoir from which the foregoing facts are gathered, Bredichin argues that parabolic orbits may be converted into elliptical ones not only by planetary perturbations, but by the action of the sun causing disruption of nuclei, some portions of which will be driven into elliptical orbits whilst others fall into hyperbolic orbits.[o]

Supposing a comet to become split up into 2 or more portions, it is conceivable that each might travel round the Sun in an orbit of its own, with an independent period of revolution, and become in all senses an independent body. Undoubtedly there would be a family resemblance between the orbits as regards size, shape, and position relatively to the Sun, and the term "a family of comets" has come into use in this connection.[p] This certainly has often led astronomers engaged in computing orbits to draw (or jump at) conclusions of identity. It cannot be said that any case yet put forward of a broken-up comet has yielded satisfactory evidence of the identity of any parts of such a comet; but a German astronomer, Berberich, some 15 years ago, offered some suggestions on this subject which I give for what they are worth. Speculation on the subject has been rife since 1770, when Lexell's Comet was discovered, and found, as was supposed, to have a period of only 5½ years. It was therefore expected that, allowing for planetary perturbations, it would be seen again in 1779, but it was not seen, and never has been seen since, though not a few comets which have been visible during the last 140 years have been suggested to be identical with Lexell's.

The German astronomer just named is responsible for the assertion that the great Comet of September 1882 (iii.), was divided into 4 parts, each of which became a comet revolving round the Sun; the respective periods being 670, 770, 880, and 960 years. He went on to suggest that the Comets of 1668, 1689, 1835 (*sic*), 1880 (i.), and 1887 (i.) had a similar

[o] *Bulletin de L'Acad. des Sciences de St. Petersbourg*, 5th series, vol. xiv, p. 183. May 1901.

[p] But this expression is also used in connection with groups of comets associated with planets, to be treated of in Chap. IV (p. 41, *post*).

common origin in some giant comet, centuries previously. The comet discovered by Coggia and Winnecke, in November 1873, as it has an orbit resembling Biela's, may have sprung from a common stock, whilst its orbit is very similar to that of 1818 (i.). Similar relationships may be traced between Barnard's Comet of 1884 (ii.), Wolf's Comet of 1884 (iii.), Wolf's Comet of 1875,[q] and Coggia's Comet of 1874 (iii.); also between the comets of 1807, 1880 (v.), 1881 (iii.), 1888 (i.), 1889 (iv.), and 1892 (i.). The periods of the first 5 range from 1700 years to 5130 years. The period of the last named is 20,200 years, its greater length being due to the influence of Saturn. I give all these details on the authority of Berberich, but do not hold myself responsible for them.

A less ambitious and more justifiable scheme of grouping than any of those just mentioned is that which puts together the comets (all of them "great" ones) of 1668, 1843 (i.), 1880 (i.), 1882 (iii.), and 1887 (i.). The members of this group all have orbits remarkable for their small perihelion distances, and also have elements almost identical, yet they cannot possibly be different appearances of one and the same comet. Their elements are:—

	1668	1843 (i.)	1880 (i.)	1882 (iii.)	1887 (i.)
	°	°	°	°	°
π =	277	278	278	276	274
☊ =	357	1	356	346	337
ι =	35	35	36	37	43
q =	0.004	0.005	0.005	0.008	0.005
Motion =	Retrograde	Retrograde	Retrograde	Retrograde	Retrograde
ϵ =	1.0	0.9998	0.9994	0.9964	1.0

What these figures mean is this: that we have been visited by 5 comets pursuing nearly the same orbits, and following one another round the Sun at varying intervals as if they

[q] *Sic in orig.* in *Sirius*, vol. xxi (N.S.), p. 153. July 1893. This "1875" is misprinted as "1885" in *Journ. B.A.A.*, vol. iii, p. 460, July 1893, but both dates are wrong; Wolf had no comet in either year, and I have been unable to unravel the mystery of the mistake.

had at some time formed one body, or had come from the same source of origin. It is conceivable that the 1843 Comet might be identical with the 1668 Comet, but the 1880 and 1882 Comets can by no possibility be either identical with one another or identical with either of the 2 earlier ones, for all the computers who investigated the orbit of the 1882 comet assigned to it periods varying from 600 to 900 years.[r]

These comets are not only kindred in regard to their orbits but physically very much alike as regards size and brilliancy. Moreover they came to the Sun from the direction of the star Sirius (α Canis Majoris), that is, from the direction *from* which the Sun is moving with respect to the stars, and escaped notice in the Northern Hemisphere until near perihelion; and passed nearly half-way round the Sun in a few hours at very short absolute distances from the Sun.

On the point of jumping at conclusions as to the identification of comets, Young has remarked that caution must be observed, for:—"Even if the result of this investigation appears to show that the comets are probably identical, we are not yet absolutely safe in the conclusion, for we have what are known as 'cometary groups'. These are groups of comets which pursue nearly the same orbits, following along one after the other at a greater or smaller interval, as if they had once been united, or had come from some common source. The existence of such groups was first pointed out by Hoek of Utrecht in 1865. The most remarkable group of this sort is the one composed of the great comets of 1668, 1843, 1880, and 1882; and there is some reason to suspect that the little comet visible on the picture of the Corona of the Egyptian Eclipse [of 1882][s] also belongs to it. The bodies of this group have orbits very peculiar in their extremely small perihelion distance (they actually go within $\frac{1}{2}$ a million miles of the Sun's surface), and yet, although their elements are almost identical they cannot possibly all be different appearances of

[r] For more on this subject, see *Journal, B.A.A.*, vol. xi, p. 248, April 1901, quoting from a memoir by Kreutz, *Untersuchungen über das System der Cometen*, 1843, &c. [no. 1. of "Abhandlungen . . . zu den Astronomischen Nachrichten". Kiel. 1901.]

[s] See p. 227 (*post*).

one and the same comet. So far as regards the Comets of 1668 and 1843, considered alone, there is nothing absolutely forbidding the idea of their identity: Perturbations might account for the differences between their 2 orbits. But the comets of 1880 and 1882 cannot possibly be one and the same; they were both observed for a considerable time and accurately, and the observations of both are absolutely inconsistent with a period of 2 years, or anything like it. In fact for the Comet of 1882 all of the different computors found periods ranging between 600 and 900 years." [t]

Hoek has suggested a considerable number of other comet groups besides those already named.[u]

The immense mass of material ejected from the heads of comets and added to the tails has suggested that comets in time must perish from the exhaustion of their material. The idea seems startling, but it cannot be said to be *primâ facie* unsound, and there certainly are facts to support it. Miss Clerke's reflections on this subject are to the point:—" Kepler's remark that comets are consumed by their own emissions, has undoubtedly a measure of truth in it. The substance ejected into the tail must, in overwhelmingly large proportion, be for ever lost to the central mass from which it issues. True, it is of a nature inconceivably tenuous; but unrepaired waste, however small in amount, cannot be persisted in with impunity. The incitement to such self spoliation proceeds from the Sun; it accordingly progresses more rapidly the more numerous are the returns to the Solar vicinity. Comets of short period may thus be expected to *wear out* quickly." [x]

In the light of all that has been said on the subject in these pages and elsewhere, can any summary statement be made in answer to the question, " What are comets made of?"

I give, under great reserve, the answer: that probably the heads are a mixture of solid and gaseous matter, and that

[t] C. A. Young, *General Astronomy*, p. 434.

[u] See his papers in *Month. Not. R.A.S.*, vol. xxv, p. 243, June 1865; *Ib.*, vol. xxvi, p. 1, Nov. 1865; *Ib.*, vol. xviii, p. 129. March 1868.

[x] A. M. Clerke, *Hist. of Ast.*, 4th ed., p. 91. Kepler's account will be found in *De Cometis.*, *Op.* vol. vii, p. 110.

the tails are gaseous, the gaseous matter in the tails being the result of the volatilisation of the solid matter of the heads or of some of it. The connection between Comets and Meteors (to be unfolded in a later chapter) seems to imply the presence in comets of solid matter; and the spectroscope shows that gases also are a constituent of many, or of all, comets. To say what is the size of the solid particles is impossible: paving stones, brick-bats, and grains of sand have in turn been suggested by people fond of speculation.

CHAPTER III.

THE TAILS OF COMETS.

Tails usually a prolongation of the Radius Vector.—Occasionally the tail faces the Sun.—Then called a "beard".—Comets with several tails.—The Comet of 1825.—*The Comet of* 1744 *with* 6 *tails.—Curvature of Tails.—Repulsive Action of the Sun on Tails of Comets.—Changes of Direction of Tails.—Tails probably hollow cones or hollow cylinders.—Vibration of Tails.—Jets of Light in the heads of Comets.—Formation of Envelopes.—Fans of Light.—Abnormal Changes in the Tails of certain recent Comets.—Swift's Comet of* 1892 (i.).—*Brooks's Comet of* 1893 (iv.).—*Observations by Barnard.—Morehouse's Comet of* 1908 (iii.).—*Speculations as to the formation of Tails.—Bredichin's classification of Tails.*—(1) *Long straight Rays.*—(2) *Curved plume-like Trains.*—(3) *Short, stubby, and sharply curved brushes of light.—What is the material of which Tails are made?—Speculation on the subject not very profitable.—Electricity and Light-pressure probably co-operating influences.—Summary by Maunder.*

Some of the more usual and prominent features connected with the tails of comets from the standpoint of recorded facts will now be dealt with, leaving more or less on one side the vast mass of theory and speculation which surrounds the subject.

It was observed by Peter Apian that the trains of 5 comets seen by him between the years 1531 and 1539 were turned *from* the Sun, forming more or less a prolongation of the radius vector, which is the name given to an imaginary line joining the centre of the Sun and the centre of the head of a comet.[a] This may be regarded as a general rule, although exceptions do occur. Thus the tail of the Comet of 1577 deviated 21° from the line of the radius vector. Valz stated that the tails of the Comets of 1863 (iv. and v.) deviated from the *planes of the orbits*, and that only 2 other comets are known the tails of which did the same. In some few instances, where a comet has had more than one tail, the second

[a] *Comptes Rendus*, vol. lviii, p. 853. 1864.

tail has extended more or less *towards* the Sun. Such a tail has been sometimes spoken of as a "beard". Amongst the recent comets which have had such an appendage may be mentioned those of 1823, 1848 (ii.), 1851 (iv.), 1877 (ii.), and 1880 (vii.).

Although the credit of noticing that the tails of comets are usually turned away from the Sun is ascribed to P. Apian, the researches of E. Biot shows that this fact was noted by the Chinese long before the time of Apian, to wit, in the year 837 A.D., when a brilliant comet was visible.[b]

Although comets usually have but one tail, 2 are not uncommon, whilst even that number is often increased by the presence of slender streamers, which are virtually independent tails. The great Comet of 1825 seen by Dunlop in Australia had 5 tails, and that of 1744 had as many as 6. This last statement depending as it did, for a long time, on the unconfirmed testimony of a Swiss astronomer named De Chéseaux, used not to be believed, but there is now no doubt as to its authenticity.[c] The 3rd Comet of 1903 (Borelly's) was photographed at Greenwich showing 9 tails, all told, but they required some looking for.[d] It seems certain now that photography often reveals tails of which telescopes and naked eyes take no account.

When a comet has 2 tails it may happen that both are of about the same size and length; or that the second tail is not so much to be regarded as a second independent tail as a little offshoot of one main tail. In this case the secondary tail is usually less bright and much shorter than the main tail. For instance, Pons's long-period Comet of 1812 at its reappearance in 1886 had on December 29 a principal tail 8° long and a secondary one very faint and only 3° long; but the secondary tail is not always the shorter of the 2. Swift noted the secondary tail of the Comet of 1881 (ii.) to have been 55° long —the longest secondary tail on record.[e]

[b] *Comptes Rendus*, vol. xvi, p. 751. 1843.

[c] See Chap. X. (p. 127, *post*).

[d] *Month. Not. R.A.S.*, vol. lxiv, p. 84. December 1903.

[e] *Work of the Warner Observatory*, vol. i, p. 22.

Curvature of the tail is a very common feature, especially in the case of large naked-eye comets. Sometimes the appearance is that of a tail originally straight, which has become bent into the form of a cavalry sabre; at others the bending is accompanied by a lateral swelling out at the extremity, after the fashion of a Turkish scymitar. The Comets of 1844 (iii.) and Donati's Comet of 1858 are good examples of comets with curved tails, whilst the great Comet of 1882 was a notable example of a scymitar tail at one period of its visibility—but of that comet more hereafter, for other reasons.

After a tailed comet has passed round the Sun at the epoch of perihelion and starts on its way back into Space the tail usually more or less *precedes* the head instead of following it. This fact opens up a difficulty which can be stated more easily than it can be solved. Whilst the doctrine of Gravitation assuredly applies to comets which come within the reach of the Sun and are thus drawn towards the Sun, yet even before as well as after they have reached their least distance from the Sun they mysteriously become subject to a repulsive solar action of some sort which it is difficult to define or explain, which has been truly said to have "no known counterpart in any other observed fact of nature", and weakens the theory of Gravitation.

The Comet of 1769 had a double curved tail thus ∽ according to La Nux, who observed it at the Isle of Bourbon. The great Comet of 1882 exhibited a striking and uncommon form of tail, some account of which will be given in a later chapter.[f]

Fig. 10 illustrates the changes in the direction of the tail of a comet as it comes up to the Sun, passes its perihelion, or point of nearest approach to the Sun, and then goes away from the Sun. It is intended to show that a tail which, when the comet is still far off from the Sun, is straight becomes curved as the comet's motion becomes more rapid. That as the curvature of the orbit gets sharper so will the tail exhibit itself as curved will be seen from inspection of the diagram to

[f] See Chap. X. (*post*).

be a natural result of things, independently of the question what is the form of the tail, whether cylindrical, or flat, or solid, or hollow.

As regards the actual formation of comet tails, probably in all cases they are hollow, but whether hollow cones or hollow cylinders depends on circumstances. In either case this theory accords, as it naturally should do, with the observed fact that single tails usually are divided in the middle by a dark band, the brilliancy of the margins exceeding that of the more central portions; but it must be confessed that this theory breaks down where the outer edges of a tail are fainter

Fig. 10.

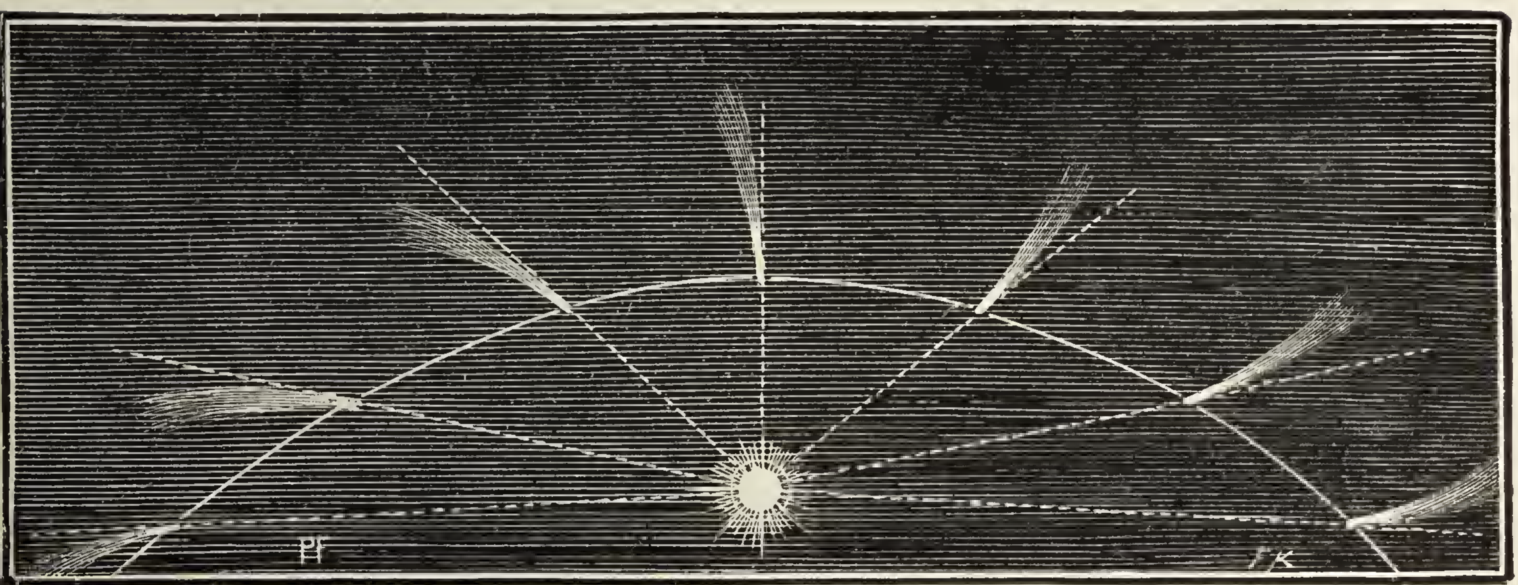


DIAGRAM ILLUSTRATING CHANGES IN THE DIRECTIONS OF THE TAILS OF COMETS.

than the centre, which seems to have a luminous spine of light running down it.[g] Where the tail increases in width towards its extremity it is permissible to suppose that its general form is that of a hollow cone; where the width is fairly uniform from end to end the tail may be regarded as a hollow cylinder.

The trains of some great comets are said to have been seen to vibrate in a manner somewhat similar to the Aurora Borealis. The tails of the Comets of 1618 (ii.) and 1769 may be cited as instances; the observer in the latter case was

[g] The great Comet of 1874 (Coggia's) had at one time such a spine of light running down it.

Pingré, whose great knowledge of comets adds weight to his testimony. The vibrations commenced at the head and appeared to traverse the whole length of the comet in a few seconds. It was long supposed that the cause was connected with the physical nature of the comet itself; but Ollers pointed out that such appearances could only be fairly attributed to the effects of the Earth's atmosphere, and for this reason:—"the various portions of the tail of a large comet must often be situated at widely different distances from the Earth; so that it will frequently happen that the light would require several minutes longer to reach us from the extremity of the tail than from the end near the nucleus. Hence, if the coruscations were caused by some electrical emanation from the head of the comet, even if it occupied but one second in passing over the whole surface, several minutes must necessarily elapse before *we* could see it reach the tail. This is contrary to observations,[h] the pulsations being almost instantaneous." Instances of this phenomenon are not very common; Coggia's Comet of 1874 is the most important modern example. An English observer at Hereford named With, well known for his astronomical mirrors, noticed an "oscillatory motion of the fan-shaped jet upon the nucleus as a centre, which occurred at intervals of from 3 to 8 seconds. The fan seemed to 'tilt over' from the preceding to the following side, and then appeared sharply defined and fibrous in structure; then it became nebulous, and all appearance of structure vanished."[i] A flickering of the tail of this comet was observed by Newall.

The mention of the word "jet" in the preceding quotation suggests the necessity of something more being said, based on this word. Without being able exactly to dogmatise on the subject, it seems certain that not a few of the larger comets which have been subjected to telescopic scrutiny during the last half-century have exhibited changes which can only be compared to the appearance of a jet of water rising from the nozzle of a fountain and rising higher and higher, until at last

[h] *Mém. Acad. des Sciences*, 1775. p. 302.

[i] *Ast. Reg.*, vol. xiv, p. 13. Jan. 1876.

June 26.

June 28.

June 30.

July 1.

July 6.

July 8.

THE COMET: (1860, iii.):

(*Drawn by Cappelletti and Rosa.*)

P. 26.

gravity overcomes the pressure upwards of the water and the water begins to curl over, umbrella fashion, and to fall to the ground.

Several modern comets exhibited what may be termed jet features. The accompanying illustrations [Plate III, Figs. 11–16] bring out this idea without the necessity of any verbal description.

Closely akin to the jets of light just alluded to are the "envelopes" of which observers of large comets nearly always make mention. The best idea of what these envelopes are, and of the way in which they are given off, is to be had by comparing the nucleus of a comet to the core of an onion, and the successive envelopes of the comet to the successive skins of the onion as they come off, one by one. The existence and developement of these envelopes will usually become known and proceed somewhat in the following manner. If the comet, already possessing a bright nucleus, is approaching the Sun (and the Earth) and day by day becomes brighter, there will sooner or later be noticed something in the form of an arc or a semi-circle of light half encompassing the nucleus on the side away from the Sun. This arc of light (the outline of which will be not truly semi-circular but parabolic) will gradually stretch out and become the commencement of a tail, or if a tail already exists will become lost in it. Other arcs of light will one by one manifest themselves and spread as the first one did, so that eventually there may be half a dozen or more of these envelopes, concentric with the first, and remaining with a certain amount of permanency grouped around the nucleus. It will sometimes be seen that the innermost arc is linked with the nucleus by one or more bridges, as they may be called (often fan-shaped), the innermost end of the bridge joining on to and forming part of the nucleus, whilst the outermost extremity is lost in the nearest arc which forms a temporary boundary to it. It must be pointed out that the arcs and fans spoken of are not truly such, but only appear to be such by the unavoidable effect of perspective. The true form of an arc under such circumstances is what is called a "paraboloid of revolution"

surrounding the nucleus on all sides except that turned from the Sun. Accordingly, nothing within the easy reach of an ordinary reader will bring the actual condition of things more clearly home to him than the simile of the onion, supplemented, as it may be, by a personal inspection of a simple jet of water rising straight up from the nozzle of a fountain, and presenting, when looked at from a near position, the outline of a curvilinear bell tent.

The formation of envelopes in the head of a comet, when such show themselves, will be easily understood by an attentive consideration of Fig. 17, the idea of which is due to Newcomb and Holden.[k]

The diagram is intended to represent four successive stages

Fig. 17.

IDEAL DIAGRAM OF THE FORMATION AND DEVELOPEMENT OF "ENVELOPES" IN THE HEAD OF A COMET.

in the developement of the envelopes. The Sun is supposed to be above the diagram, and the tail below. When the appearance is as **a**, the cometary matter, whatever it may be, has just begun to start rising upon the nucleus. In **b** it has risen higher, and spread on each side wider. In **c** it has spread still further, and may be regarded as distinctly moving away from the nucleus but encompassing it on 2 sides though at a distance. Finally in **d** the movement and developement has proceeded so far, that the uppermost portions of the cometary matter has become so attenuated as often to have almost disappeared, the larger portion of the envelope having,

[k] *Astronomy for Schools and Colleges*, 4th Ed., p. 391.

in a sense, lost its individuality and become merged in the tail. Before the stage **c** is reached, it will often happen that a second envelope will have begun to rise as at **a**, so that two or even three envelopes, more or less concentric, may be visible at the same time, one inside another.

If, with the foregoing description clearly in his mind of the envelopes usually seen in the heads of large comets, the reader will turn to Chapter IX (*post*), and will examine the illustrations there given of the heads of the Comets of 1858 (vi.), 1861 (ii.), 1862 (iii.), and 1874 (iii.) in particular, he will have no difficulty in realising the features which generally present themselves in the heads of large comets ; and which from time to time are described by different observers, under the varying terms of "jet", "fan", "luminous sector", "envelope", and so on. Bessel considered that the changes which he observed in the head of Halley's Comet in 1835 justified him in assuming that a systematic oscillation of the head and nucleus took place in the plane of the comet's orbit, almost amounting to a movement of rotation.[1]

Three comets of recent date are noteworthy as having undergone tail transformations quite without precedent, though the credit of our knowledge respecting them is in part due to the assistance of photography, which has furnished records of changes more full and more accurate than eye observation could have done.

The first of these comets is Swift's Comet of 1892 (i.). On April 4, the tail was 20° long, bifid, straight, and slender. Between the 2 branches scarcely any cometary matter was visible. The next morning a new tail had appeared in the interspace, and each of the 3 main tails was found to be made up of several, side by side. At least a dozen distinct streaks of cometary matter could be counted. After the lapse of another day one of the original 3 tails had vanished and the other 2 had become blended. Then one of these brightened up and the other faded away. The bright one had a sharp

[1] His observations and opinions will be found in the *Connaissances des Temps*, 1840, "Additions," p. 79.

bend in it, as if it had encountered and been turned aside by some obstacle. Near the point of deflection there were 2 dark spots in the brightest part of the tail. Finally the surviving tail split up into 6 strips. All these changes, and some others, took place in the space of 5 days.

Brooks's Comet of 1893 (iv.), discovered on Oct. 17, started with a main tail which was straight whilst there was also a secondary tail. A photograph taken on Oct. 21 revealed extraordinary changes which Barnard thus describes:—

"It presented the comet's tail as no comet's tail was ever seen before. The graceful symmetry was destroyed; the tail was shattered. It was bent. distorted, and deflected, while the larger part of it was broken up into knots and masses of nebulosity, the whole appearance giving the idea of a torch flickering and streaming irregularly in the wind. The short northern tail was swept entirely away, and the comet itself was much brighter. The very appearance at once suggested an explanation, which is probably the true one. If the comet's tail, in its flight through space, had suddenly encountered a resisting medium which had passed through the tail near the middle, we should have precisely the appearance presented by the comet. It is not necessary that the medium should be a solid body; if it possessed only the feeblest of ethereal lightness it would deflect, distort, and shatter the tail. What makes this explanation all the more probable is that the disturbance was produced from the side of the tail that was advancing through space." [m]

Another recent comet which displayed extraordinary changes in its tail was Morehouse's Comet of 1908 (iii.), watched with great success by a numerous body of photographic-astronomers. Amongst other things some outbursts in the nature of explosions seem to have occurred in the tail. This comet is also noticeable from the fact that it travelled from Pole to Pole during the period of its visibility; and having been circumpolar during many weeks in the autumn of 1908, continuous observation for many consecutive hours was possible, which much facilitated the photographing of it.

This comet was unique from the first. The art by which it was discovered (photography) so faithfully followed its every movement, from such variety of longitudes, that a more

[m] *Popular Astronomy*, vol. i, p. 146. Dec. 1893.

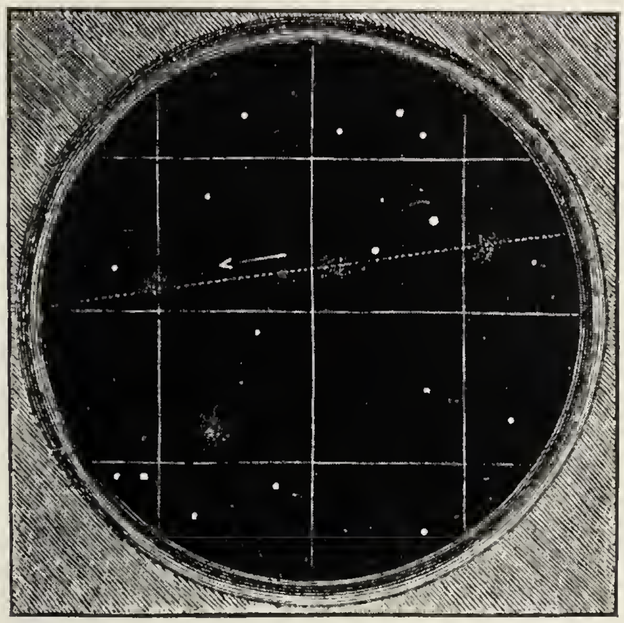


DIAGRAM.

TO ILLUSTRATE THE RECOGNITION OF A COMET AS DISTINGUISHED FROM A NEBULA.

BROOKS'S COMET (1893, iv.). October 21.

P. 30.

perfectly continuous life history of a comet has never been obtained. Moreover those who studied it were bounteously rewarded by the number of unexpected transformations which they saw.

The first of these transformations occurred from September 30 to October 2. On September 29 the tail showed no signs of the coming catastrophe, being perfectly normal. During the next 24 hours it presented unprecedented activities. Its appearance changed continuously throughout the night of September 30, these changes ending on October 1 in a complete disruption. The photographs on the former date showed a bright contracted coma joined to the tail by a narrow tapering neck. Near the head the tail was strong, violently twisted, and cyclonic in form. At about 1° from the head it spread into a broad fan-shaped mass which was very irregular on the *sp* side, and extended for 8° as a bright curved projection on the *nf*. October 1 will be memorable as the date on which the comet lost its tail; and it disappeared to all but the photographic eye. The great masses which had formed the tail on the previous night were now seen some 2° out from the coma and attached to it by slender streamers. The nucleus was the same as on the former plate. It was the tail that was gone. Photographs of October 2 show 3 distinct tails; one broad and fan-shaped, and two smaller ones. They were all faint and changing slowly.

The second great disturbance began on October 15. This was wholly different from the one just described. The plate of October 14 showed a tail at least 7° long with distinct lines running through it longitudinally. It was bright, with marked irregularities near the head. The 12 hours that followed recorded extraordinary changes. The comet had broken in two. The photographs taken in the United States show two great condensations in the tail about $\frac{1}{2}$° from the head. A bright, short, spike-like projection, with one end between the two masses and the broad end attached to the coma, formed the new tail. The old tail was very faint, irregular in outline, and curved on its *sp* side. Photographs taken at the observatory of Geneva by Pidoux at 7^h 35^m

T. M. E. C. and at Juvisy by Quenisset at 8^h 55^m T. M. E. C. show great bends (the latter one the stronger) in the tail at about the place where the condensations appear. It therefore seems that these masses were not thrown out by the comet's head, but caused by a localisation of the particles in the tail due to some encountered force. On the plate of October 16 these masses can still be seen about $1\frac{1}{2}°$ from the head and connected with the newly-formed tail by slender threads of light.

About the middle of November a third distinctive feature developed. The comet was now characterised by long slender rays extending at measurable angles to the tail, and by undulations in the body of the tail itself. This appearance is most striking in the photograph of November 15 where slender streamers shoot out from the main body of the tail with tremendous velocity. The two on the *s p* side have very interesting structures. They are made up of still finer rays which cross each other alternately, and at the end make a bend in the direction of the comet's motion and then return to their original direction. At about 5° from the head the tail makes an abrupt turn toward the N. as if it had encountered a resisting medium. It is strongly convoluted on the *n f* side and full of detail through its whole length. On the following night, November 16, the entire aspect had changed. The coma was much stronger both visually and photographically. The tail showed marked signs of pulsations. On November 18 the comet was a beautiful object. The slender straight rays were predominant. The tail was broken into waves and a conspicuous dark streak extended along its N. side for some distance from the head.

On November 19, the head was seen to give off straight jets at small angles. The tail for a short way back was composed of individual strands which intertwined like the strands of a rope, whilst near the end they separated into broad ribbon-like bands.

It repeatedly lost its tail and formed new ones. Instead of submissively settling down to one of the three established types of comet tails, it took on a variety of types in one

MOREHOUSE'S COMET (1908, iii.). October 15.

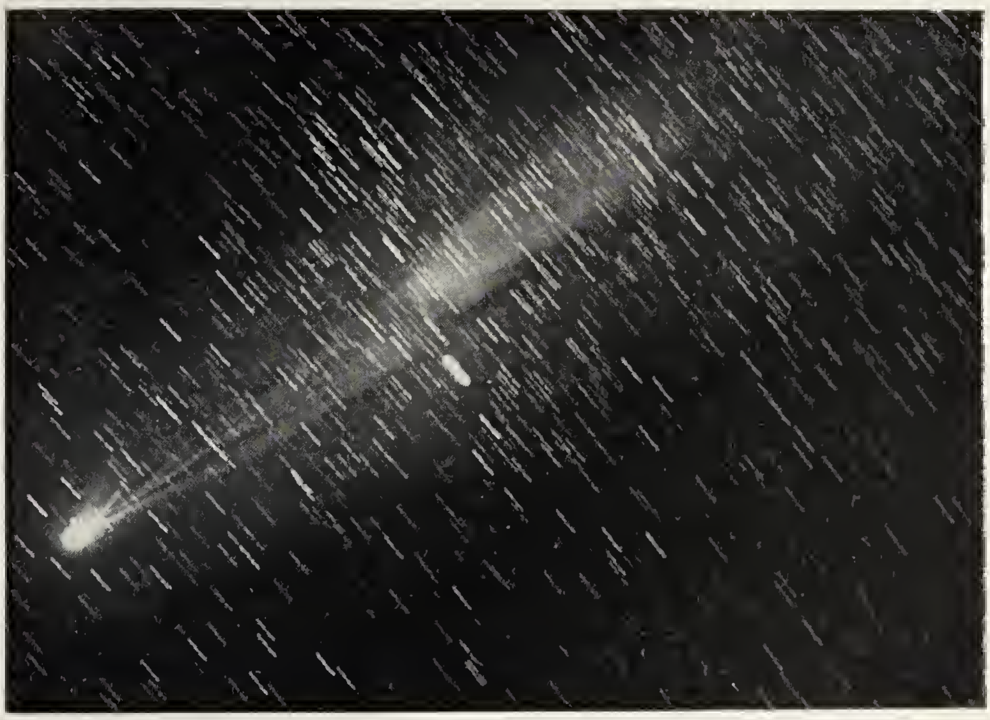
(*Photographed by P. Morris.*)

MOREHOUSE'S COMET (1908, iii.). October 30.

(*Photographed by P. Morris.*)

P. 32 *b*.

September 30, 17^h 16^m G.M.T.



October 1, 19^h 43^m G.M.T.

MOREHOUSE'S COMET (1908, iii.).

(*Photographed at the Yerkes Observatory.*)

P. 32 *c*.

October 15, 14^h 31^m G.M.T.

November 15, 12^h 6^m G.M.T.

MOREHOUSE'S COMET (1908, iii.).

(*Photographed at the Yerkes Observatory.*)

day. Condensations, waves, straight rays, twisted funnels, and numerous unrecognised forms made up its wonderfully active tail.

Not only was it exceptional in its actions, but also in its constituent material. Its spectrum was quite different from previous comets. In place of the familiar hydrogen gas was found the poisonous cyanogen element. Other ingredients not recognised seem to have been present. Altogether it gave to astronomers a wealth of data which it will require years to digest and interpret properly.[n]

The literature of comets' tails may be likened to the literature of Free Trade and Tariff Reform in the world of Politics: it is superabundant and more than superabundant. In the pages which have gone before I have somewhat exhaustively described these tails from the standpoint of the mere star-gazer, armed, or not, as the case may be, with a telescope. It remains now to consider, and I shall do so very briefly, some of the more definite conclusions which have been arrived at as to the theory of tails; by which is meant the dynamical circumstances under which they are usually evolved. Speculation[o] as to this has proceeded of late years on a gigantic scale, and vast quantities of ink and paper have been (as I think fruitlessly) expended on the subject, the details of which would not have much interest for the general reader.

It is to a Russian astronomer, Bredichin,[p] that we owe what seems the most thoughtful and best classification of comets' tails; and his conclusions are the more valuable that they do not run into extravagances of speculation. Briefly stated, he divides the tails of comets into 3 classes or types:—

[n] The foregoing account of Morehouse's comet is mainly founded on information kindly supplied to me in MS. by Morehouse himself for the purposes of this volume.

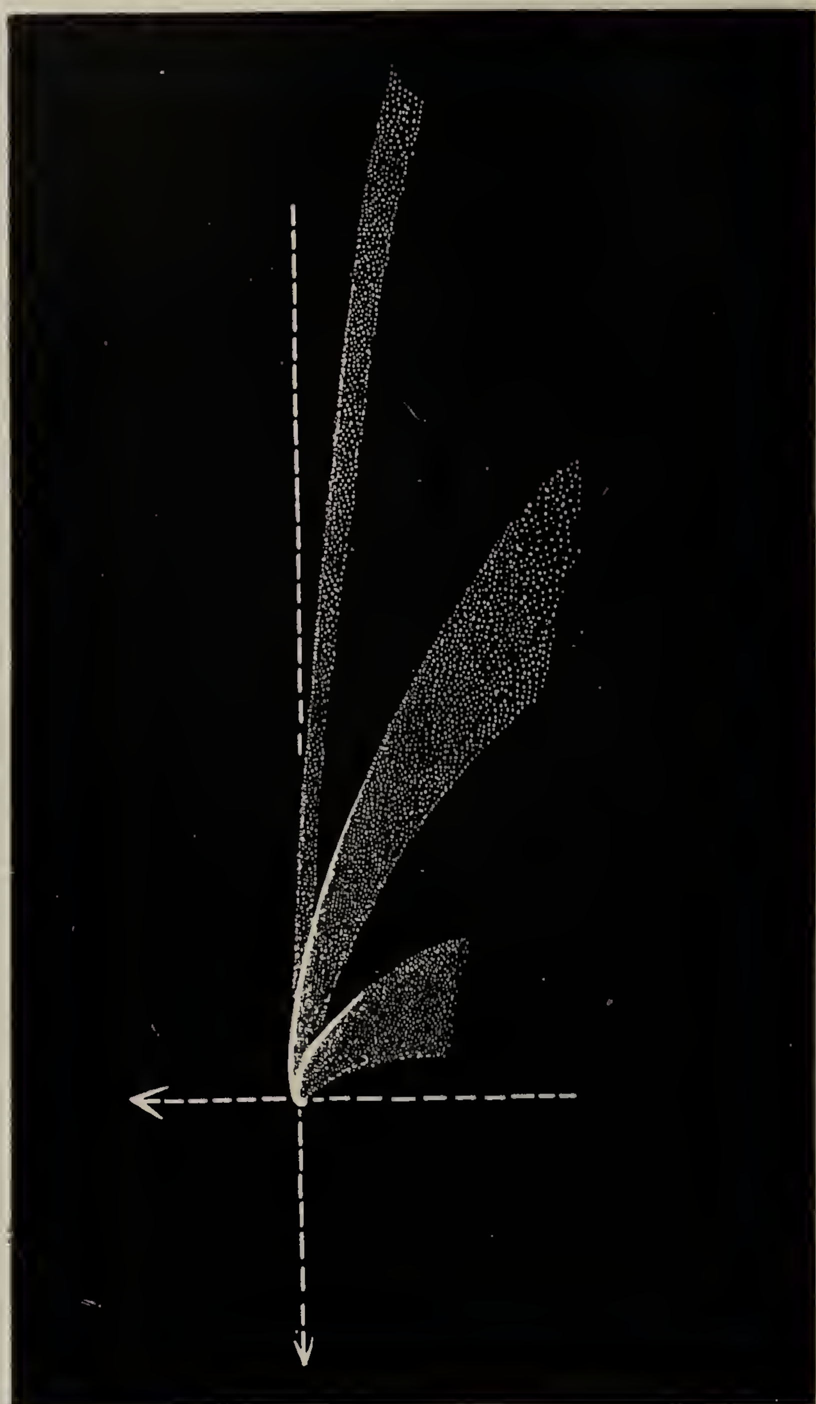
[o] A sort of index to some of this will be found in *Month. Not. R.A.S.*, vol. lxiv, p. 347. Feb. 1904.

[p] This gentleman's name is frequently spelt Bredikhine, I suppose in consequence of the difficulty of transliterating Russian spelling into Roman spelling, but the spelling in the text was his own way of rendering his name when writing in Roman characters, and in the French language.

(1.) Long straight rays.
(2.) Curved plume-like trains.
(3.) Short, stubby, and sharply curved brushes of light.

Tails which belong to Bredichin's first type are formed of matter upon which the Sun's *repulsive* action is supposed to

Fig. 26.



BREDICHIN'S THREE TYPES OF COMET TAILS.

be 12 or more times greater than the *attractive* action due to Gravitation; so that the particles quit the head of the comet with a relative velocity which is gradually increased as they recede, until it becomes enormous. The straight rays noticed

in many of the engravings of the tail of Donati's Comet of 1858 are streamers of this type, composed, according to Bredichin, of hydrogen.

Tails of the second type are by far the most common, and in them the repulsive force is much less than in the first type, and is least of all at the inner edge of the tails of this type. It may be supposed that such tails are composed of some hydro-carbon gas.

Tails of the third type, examples of which are not numerous, owe their short stubby form to the twin facts that the repulsive force to which they are due is only a fraction of Gravitation; and that they are composed of something much heavier than is the case with the other kinds of tails, namely, the vapour of iron, with possibly an admixture of the vapours of other substances, especially sodium.

Thus far we have been considering the tails of comets looked at as regards their whole length, and the consequent outlines which they exhibit, but something must be said as to where the material of the tail comes from, and how it is evolved. Here again, whilst we can see many interesting transformations going on there is still the difficulty to be faced of what is the material and whence come the boundless supplies which mark the career of all the large and brilliant comets which we sometimes see and can always read about.

Of course the obvious and necessary answer is that this material is ejected from the nucleus, a fact which will be fully realized by the most cursory inspection, say for instance, of Plate III (*ante*), but no clue is afforded us as to what the material is, and speculation, it is admitted, is futile.

Speculation has been indulged in by many astronomers as to what becomes of the matter ejected from the heads of comets which after forming for a while part of the tail goes off into Space. Is it simply dispersed in Space, or what happens?

The generally accepted idea is that the fragments of a comet thus sent adrift are first of all dispersed hither and thither through Space, where if a planet falls in with them it annexes them, and they become, shall we say, "shooting stars" to that

planet, be it the Earth or some other planet; and help in an infinitesimal degree to feed that planet with new material from an external source of supply.

It must be confessed that progress in the collection of facts up to this point has done little or nothing to settle the questions, "Why should any comet have a tail?" and "What is the nature of the Solar or other influence which causes tails?" Many have been the sober, and still more the ridiculous, suggestions which have been put forth on this subject, but it may safely be said, following Olbers, Bessel, and Sir J. Herschel, that electricity, operating in some unknown and indefinite way, is the primary agent in setting on foot all cometary tails, but as to why and how, there is no agreement amongst astronomers.

As an alternative to, or rather, a co-operating force with, electricity much support has been accorded to the idea that "Light-Pressure" is now and again (or always) to some extent concerned in the repulsive action of the Sun on the tails of comets. The subject of Light-Pressure is one which belongs rather to the domain of Physics than of Astronomy. I will therefore only say that it is supposed that all sources of light exercise a certain amount of repulsion, or push, on all material substances which face the source of light, whatever may be the material, or whatever the source of the light.

Maunder has summarised the questions both of the heads and of the tails of comets in a way which seems to represent all that we really know. He says:—

"Though the bulk of comets is huge, they contain extraordinarily little substance. Their heads must contain some solid matter, but it is probably in the form of a loose aggregation of stones enveloped in vaporous material. There is some reason to suppose that comets are apt to shed some of these stones as they travel along their paths, for the orbits of the meteors that cause some of our greatest 'star showers' are coincident with the paths of comets that have been observed. But it is not only by shedding its loose stones that a comet diminishes its bulk; it loses also through its tail. As the comet gets close to the Sun its head becomes heated, and throws off concentric envelopes, much of which consists of matter in an extremely fine state of division. Now it has been shown that the radiations of the Sun have the power of repelling matter, whilst the Sun itself attracts by its gravitational force. But there is a difference in the action of the 2 forces. The light-pressure varies with the surface of the particle upon which it is

exercised: the gravitational attraction varies with the mass or volume. If we consider the behaviour of very small particles, it follows that the attraction due to gravitation (depending on the volume of the particle) will diminish more rapidly than the repulsion due to light-pressure (depending on the surface of the particle) as we decrease continually the size of the particle, since its volume diminishes more rapidly than its surface. A limit therefore will be reached below which the repulsion will become greater than the attraction. Thus for particles less than the $\frac{1}{25000}$ part of an inch in diameter the repulsion of the Sun is greater than its attraction. Particles in the outer envelope of the comet below this size will be driven away in a continuous stream, and will form that thin, luminous fog which we see as the comet's tail."[q]

The latest idea in tails is due to Barnard, who has suggested that there is evidence to show that the same causes (on the Sun?) which give rise to (?) auroral displays have some influence over the changes in the tails of Comets. He speaks of there being "some kind of disturbing medium in Space which can shatter and distort a tail when encountered by it."[r]

[q] E. W. Maunder, *The Astronomy of the Bible*, p. 105.

[r] *Astrophysical Journal*, vol. xxix. p. 70, Jan. 1909.

CHAPTER IV.

THE MOVEMENTS OF COMETS.

Periodical Comets.—Non-periodical Comets.—The density of Comets.—The Masses of Comets.—Lexell's Comet.—The risk of collision of Comets with the Earth.—No real danger.—The Influence of Planets on Comets very real.—Special Influence of Jupiter.—List of Comets affected by Jupiter.—Comets that are said to be associated with Planets.—The Inquiries made when a new Comet is discovered.—Old Astronomers puzzled by the movements of Comets.—Sir I. Newton's investigations.

So far as their movements are concerned comets may be divided into two classes: (1) those which may be regarded as permanent members of the solar system; and (2) those which have once, and once only so far as is known, visited the solar system. The comets belonging to Class 1 must be further subdivided into two great sub-classes: (*a*) those which have been ascertained by calculation and observation to be regular visitors to the neighbourhood of the Earth, and therefore of course permanently attached to the Sun; and (*b*) comets which are believed, so far as calculation goes, to belong to the solar system, but which as yet have only been once seen by us on the Earth. Later on we shall find it expedient to classify in more detail both types of comet, but these broad general divisions will suffice for the present.

The comets which have just been alluded to as permanent members of the solar system are called "Periodical Comets", but their periods vary between the extremes of 3 or 4 years and thousands of years. Comets with periods between 3 years and about 80 years are numerous, and may be regarded as familiar and well-recognised friends, but those whose periods run into hundreds or thousands[a] of years are those which astronomers have found reason to believe are periodic but

[a] Scheller found the period of the Comet of 1845 (ii.) to be 115,000 years!!! *Ast. Nach.*, vol. clvii, No. 3763., Jan. 18, 1902.

as to which they can do no more than prophesy that they will return to our parts of Space some day. These different circumstances bring it about that comets vary greatly in the distances to which they recede from the Sun. Whilst the orbit of the Comet known as Encke's is contained within the orbit of Jupiter, the orbit of Halley's Comet stretches out beyond that of Neptune, whilst many other comets recede to far greater distances than this. A comet can only come back to the Sun after having appeared and then disappeared, provided it moves in an elliptic orbit. The chance visitors spoken of in a previous paragraph pursue curved paths known as "parabolas" or "hyperbolas"; but the further consideration of these details is reserved for a later chapter.

The *density* and also the *mass* of comets is exceedingly small, and their tails consist of matter of such extreme tenuity that even small stars are visible through them, a fact first recorded by Seneca. That the matter of comets, whatever it may be, is exceedingly rare is sufficiently proved by the fact that instances are on record of comets having passed very near to some of the planets without disturbing in any appreciable degree the motions of the said planets. For instance, the Comet of 1770 (Lexell's) in its approach towards the Sun enveloped the satellites of Jupiter, and remained near them for 4 months without affecting them as far as we know. From this fact it can be shown that the mass of this comet could not have been so much as $\frac{1}{5000}$ that of the Earth. This comet came very near to the Earth on July 1, 1770: its distance at 5^{h} on that day being about $1\frac{1}{2}$ millions of miles. Had its matter been equal in quantity to that of the Earth its attractive force would have caused the Earth to move in an orbit so much larger than it does at present that the length of the year would have been increased by $2^{h}\ 47^{m}$, yet no sensible change took place.

The idea of any danger happening to our planet, or to any other planet, from the advent of any of these wandering strangers, may be dismissed once and for all, especially as we now know that the Earth passed bodily through the tail of the great Comet of 1861, on June 30 of that year.

As regards the influence of comets on planets, instead of comets exercising any influence on the motions of planets there is most conclusive evidence that the converse is the case—that planets disturb the movements of comets. This fact is strikingly exemplified in the history of the Comet of 1770 just mentioned. After its discovery it was found

Fig. 27.

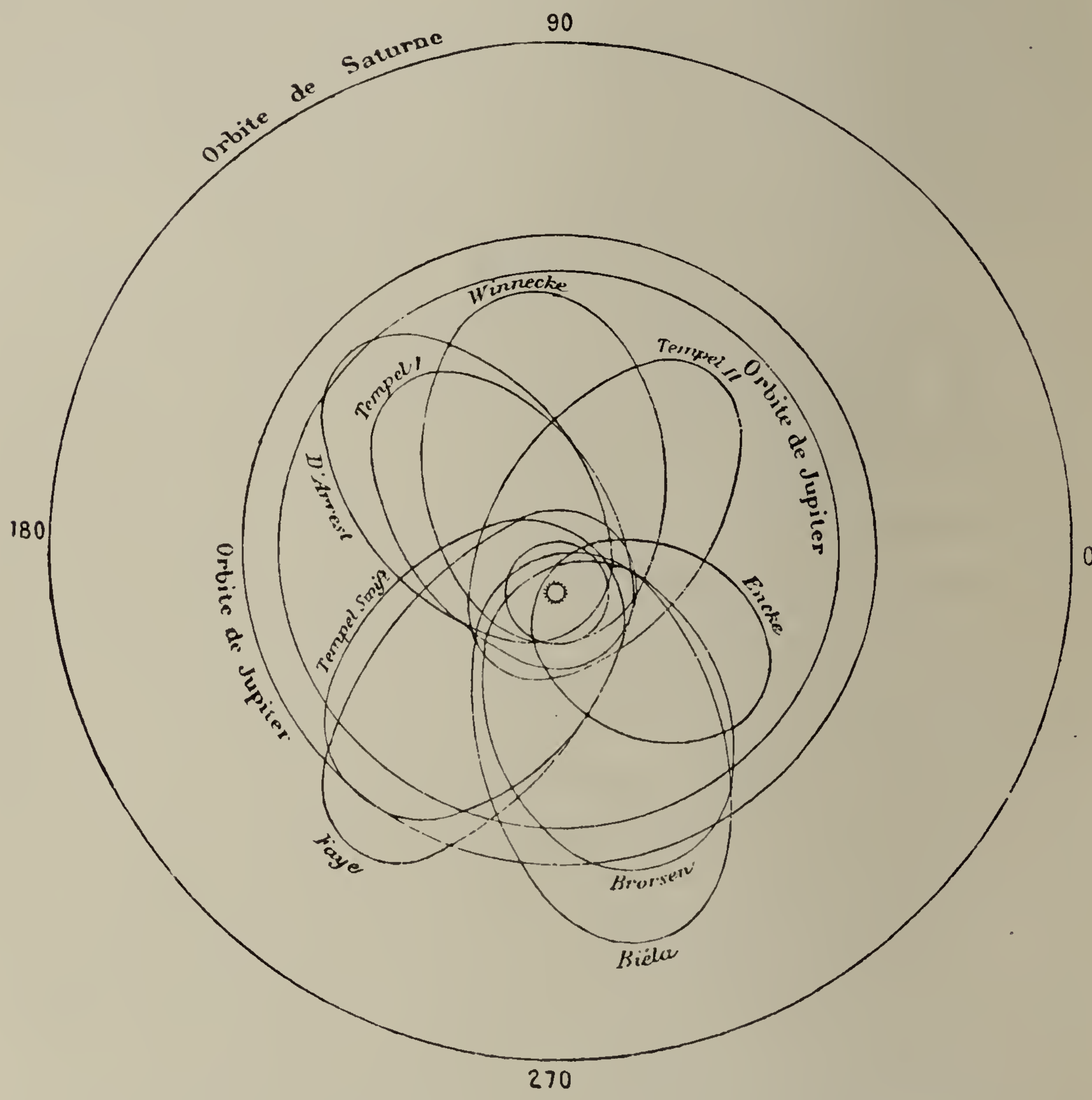


DIAGRAM ILLUSTRATING THE INFLUENCE OF JUPITER ON COMETS.

to be moving in an elliptical orbit requiring for a complete revolution only $5\frac{1}{2}$ years; yet though this comet was a large and bright one it had never been observed before, and it is doubtful whether it has ever been seen since, the reason being that the Planet Jupiter completely changed the character of its path, probably by enlarging it.

Although suggestions have been thrown out that several short-period comets discovered during recent years might possibly be returns of Lexell's Comet, yet the evidence is inadequate and unsatisfactory. Arago has a remark on this subject which deserves quotation. He says:—"Du Séjour has proved that a comet whose mass is equal to that of the Earth which would pass at a distance of 37,500 miles only, would extend the length of the year to $367^{d}\ 16^{h}\ 5^{m}$ and could alter the obliquity of the ecliptic to the extent of 2°. Notwithstanding its enormous mass and the smallness of its distance, such a body would then produce upon our globe only one kind of revolution—that of the Calendar[b]."

The influence of the larger planets on comets is now so thoroughly recognised that it has become customary to speak of such planets having "families" of comets belonging to them.

The influence of Jupiter on certain periodical comets which constitute its "family" may be inferred from Fig. 25, without the necessity of any detailed statement. Many other comets besides those included in the engraving may be regarded as subject to Jupiter's influence.[c] The following are the names of some of these arranged in the order of their aphelion distances, but the list is by no means complete, because it is limited to comets which have been observed more than once, whilst there are a number of comets which are believed to be Jupiter comets, but which have only at present been seen once. A full list of these will be found elsewhere.[d]

[b] Arago, *Pop. Ast.*, vol. i, p. 642, Eng. Ed.

[c] A large scale Plan of all the Jupiter comets up to date appears in *Astronomy and Astro-Physics*, vol. xii, p. 800. Nov. 1893.

[d] See p. 80 (*post*). Perhaps not all of those there given are Jovian comets.

Name.	Mean Distance from the Sun in Radii of Earth's orbit.
Encke's	4·09
Tempel's Second (1873, ii.)	4·76
Tempel's First (1867, ii.)	4·89
JUPITER	4·9 to 5·5
Tempel-Swift (1869, iii., 1880, v.)	5·17
Winnecke's	5·58
Wolf's	5·60
Brorsen's	5·61
D'Arrest's	5·77
Faye's	5·97
Finlay's (1886, vii.)	6·06
Biela's	6·16

It has been pointed out by W. W. Payne that there is a manifest tendency with the Jupiter comets for their perihelions to gather towards one particular region lying in the general direction of the *vernal* equinox. Jupiter's absolute motion in the region of the opposite, or *autumnal* equinox, must approximately equal his mean motion plus that of the "Sun's Way" (so-called). "Jupiter therefore would overtake or meet more comets in that part of its orbit than in others, and so the possibility of disturbing influence in that region would be greater than elsewhere." [e]

It may be remarked that great as is the attractive power of Jupiter in drawing comets into its own sphere of influence it does not follow that a comet moving in a parabolic orbit can be captured at one effort of disturbance. Thus, Brooks's Comet of 1889 (v.), now moving in an orbit of 7 years, had up to 1886 an orbit requiring 27 years for its journey round the Sun.

The idea that certain comets are associated with particular planets, or perhaps as a better way of putting it, that certain planets have certain comets in groups attached to them, is a somewhat modern one, started by Laplace, who put forth the

[e] *Astronomy and Astro-Physics*, vol. xii, p. 800. Nov. 1893.

surmise that such comets had been "captured" by the particular planets, and this theory has now met with general acceptance. Flammarion, making use of the labours of some who went before him, including especially an American named Kirkwood, who was great at coincidences, has worked out the idea in a way which has yielded some results too curious and interesting to be passed over. In addition to the Jupiter group to which reference has been made above, he finds that every major planet beyond Jupiter seems to have a group of comets revolving in elliptic orbits attached to it; and, moreover, as there is a group of comets without a known planetary leader, he makes bold to speculate that this fact is a proof that a trans-Neptunian planet exists and will one day be found. Since Flammarion published this scheme of his about a quarter of a century ago, the last-named notion has been vigorously taken up and pushed by Professor G. Forbes, but he assigns to *his* planet a period of 1076 years [f],—more than three times the period assigned by Flammarion to his hypothetical planet.

The following are Flammarion's groups, the figures appended representing in radii of the Earth's orbit the mean distances of the respective planets and the aphelion distances of the respective comets:—

2nd Group (Saturn's Family).	
SATURN	9.0 to 10.1
Tuttle's Comet	10.5
3rd Group (Uranus's Family).	
URANUS	18.3 to 20.1
Comet of 1866 (i.); and November Meteors	19.7
Comet of 1867 (i.)	19.3
4th Group (Neptune's Family).	
NEPTUNE	29.8 to 30.3
Comet of 1852 (iv.) (Westphal)	29 to 32
Comet of 1812 (Pons)	33
Comet of 1846 (iv.) (Di Vico)	34
Comet of 1815 (Olbers)	34
Comet of 1847 (v.) (Brorsen)	35
Halley's Comet	35

[f] *Month. Not. R.A.S.*, vol. lxix, p. 160. Dec. 1908.

5th Group (?).

Trans-Neptunian planet	47 to 48?
Comet of 1862 (iii.); and August Meteors	49
Comet of 1532 and 1661	48

Flammarion finally submits the speculation that the undiscovered planet must, if it be related to the comets of the 5th group, revolve at somewhere about twice the distance of Neptune, say, in a period of 300 years.[g]

Forbes's speculations do not in any way fit in with Flammarion's. Forbes gives his planet a mean distance of 100 radii of the Earth's orbit—more than double the distance assigned by Flammarion. And his group of comets is not constituted as Flammarion's is. They are 8 in number, viz.: 1556, 1840 (iv.), 1855 (i.), 1855 (ii.), 1861 (i.), 1843 (i.), 1880 (i.), and 1882 (ii.), but Forbes treats the last 3 as fragments resurrected of the Comet of 1556, which seems to have disappeared: at any rate it did not return in 1848 as expected.[h]

To complete the information respecting families of comets, it may be stated that the reason why the smaller planets near the Sun, Mercury, Venus, the Earth, and Mars have no comets under their control would seem to be that their masses (*i.e.* their powers of attraction) are so much less than the masses of the much larger distant planets; and, moreover, because comets coming up to the Sun are moving through our neighbourhood at speeds much greater than they are endued with when passing in the vicinity of the more distant planets, and can therefore more easily run away out of reach of enemies (*e.g.* planets).

When a comet is discovered the first questions asked about it by the ordinary searcher after knowledge is, "When and where can we see it?" "How long will it last?" and "Has it got a tail?"—whilst the professional astronomer wants to know, "What are its elements?" The answers to be given to the first two questions always depend upon the answer which has been given to the last question. To the majority

[g] *L'Astronomie*, vol. iii, p. 89. March 1884. I have corrected several important mistakes or misprints in the French original.

[h] *Month. Not. R.A.S.*, vol. lxix, p. 159. Dec. 1908.

of amateurs these elements are almost unintelligible; and even to advanced students they often convey only a vague idea of the true form and position of the orbit. But all questions as to orbits will be dealt with in a separate chapter.[1]

To the early astronomers the motions of comets caused great embarrassment. Tycho Brahe thought that they moved in circular orbits; Kepler suggested that comets moved in right lines. Though he was wrong as to this he was more correct in concluding that they were further off than the Moon. He formed this opinion by noting that the Comet of 1577 seemed to occupy the same position amongst the stars whether viewed from Uraniburg or from Prague, 400 miles distant. Hevelius seems to have been the first to remark that cometary orbits were much curved near perihelion, the concavity being towards the Sun. He also threw out an idea as to the parabola being the ordinary form of a comet's path, though it does not seem to have occurred to him to assume that the Sun was likely to be the focus of such a path. Borelli suggested the ellipse or the parabola as likely curves to be pursued by a comet. Sir William Löwer was probably the first to hint that comets sometimes moved in very eccentric ellipses; this he did in a letter to his "especiall good friende Mr. Thomas Harryot", dated Feb. 6, 1610. Dörfel, a native of Upper Saxony, was the first practical man, for he came to the conclusion that the Comet of 1680 moved in a parabolic orbit. Sir I. Newton also gave his attention to the subject. Confirming Dörfel, Sir Isaac showed further that the motion of that comet was in accordance with the general theory of Gravitation.

[1] See Chap. XI (*post*).

CHAPTER V.

THE DISCOVERY AND IDENTIFICATION OF COMETS.[a]

How Comets are discovered.—The great French Comet-hunter, Messier.—Much Comet-hunting now carried on in America.—Suitable occupation for amateur astronomers.—Designation of Comets.—Appropriation of observers names to Comets.—Comets only identified by the elements of their orbits.—Physical appearance of Comets no certain proof of identity.—Identity of elements not always conclusive.—Possibility of more than one Comet following the same path.—Photography as an aid to the discovery of Comets.—Ancient Chinese records of great value.—Medals for successful Comet-hunters.—Telegraph codes for transmission of cometary announcements.

"How does a new comet become known?" "Who looks out for comets?" "Who organises observations of comets?" These are questions which are often asked, and which are seldom answered in set terms in the text-books; and therefore it may be worth while to devote a short chapter to the subject.

In early times and down to the invention of the telescope and for quite a century and a half after that event, the discovery of comets may be said to have been left to chance: in other words they discovered themselves; that is to say, manifested themselves to anybody who happened to be looking at the heavens by night. It was not until 2 French astronomers towards the close of the 18th century took up the matter that any definite effort seems to have been made systematically to watch for or to search for comets. Messier, whose first comet dates from 1760, and Pons, whose first comet dates from 1802, are the 2 Frenchmen here referred to,

[a] Some useful hints on the search for and observation of comets by Denning will be found in the well-known and useful American Magazine, *Popular Astronomy*, vol. x, p. 69. Feb. 1902.

but Messier had a rival in Méchain who, between 1781 and 1799, discovered 8 comets.

Delambre has preserved the following anecdote of Messier as related by La Harpe:—"Some years ago he lost his wife: looking after her hindered him from seeing a comet for which he was on the watch, and of which Montaigne of Limoges had pilfered him. He was in despair. After a while some one spoke to him of the loss he had sustained; he replied, still thinking of his comet: 'Alas, I have found 12 comets and Montaigne has robbed me of my 13th! ' Thereupon tears filled his eyes: then remembering that it was for his wife that he ought to weep, he set to work to do so, saying, 'Ah! Poor woman,' but it was really for the comet that he was weeping." [b]

Fig. 28.

DISCOVERY FIELD OF BROOKS'S COMET (1890, ii.) ON MARCH 19, 1890.

After the beginning of the 19th century comet-hunting went out of fashion until about 1880, from which time onwards till the present year several American observers have worked most industriously and successfully in this field. Accordingly in the catalogues of comets discovered during the last 30 years the names of Brooks, Barnard, Perrine and Swift recur with monotonous frequency, and these 4 astronomers have distanced all their rivals in the world; even the Germans, who have done a great deal in connection with comet-hunting, have been distanced. Between 1877 and 1908 inclusive, no fewer than 20 first discoveries stand to the credit of Brooks, 19 to Barnard, 13 to Perrine, and 11 to Swift. These figures compare very favourably with the 13 comets discovered by Messier between 1760 and 1798 and the 27 discovered by Pons between 1803 and 1827. The

[b] *Histoire de l'Astronomie au dix-huitième siècle*, Paris, 1827, p. 770.

most successful European comet-hunter seems to have been Giacobini of Nice, who has 12 comets to his credit.

Comet-hunting is a pursuit which may well be taken up by amateurs with plenty of spare time on their hands because, if the truth must be told, it involves an immense waste of time, with results which only present themselves at long intervals. Hence the difficulty of public observatories with defined programmes taking to the work. Except for this, comet-hunting may be said to be an easy matter, given a telescope of moderate, that is, handy size (say from 4 to 6 inches of aperture); a cléar horizon in the neighbourhood of the Sun either in the W. after sunset, or in the E. before sunrise; and plenty of patient, plodding perseverance on the part of the observer. An eye-piece of low power and with a large field should always be used; whilst sometimes an enthusiastic seeker after comets will provide himself with an achromatic telescope specially designed for the work and known as a "comet-seeker", but this may be regarded in general as unnecessary. A comet-seeker is nothing more than a cheap equatorial provided with an inferior object-glass and coarsely divided circles, and contrived optically to command the largest possible field in proportion to its inches of aperture.[c] A good catalogue of nebulæ is an essential adjunct, because most comets may at a first view be easily mistaken for nebulæ, and it is only by their being possessed of movement that they can be distinguished. [See Fig. 18, Plate IV.]

Concerning the designation of comets it is expedient to say something, because there is no fixed rule, and the practice is very arbitrary and inconsistent. At its first discovery the discoverer's name is usually attached to a comet. Thus, the comet which was discovered by Morehouse on Sept. 3, 1908, was known during the whole period of its visibility as "Morehouse's Comet".[d] On the other hand Biela's Comet

[c] The comet-seeker of the Washington Observatory, aperture $4\frac{1}{2}$ inches and focal length only 2 ft. 10 in., is engraved in the *Washington Observations*, 1845, Plate II.

[d] Let me here protest against the fashion, which seems inclined to come into use in England, of designating comets according to the French idiom, whereby Morehouse's Comet would be called "Comet Morehouse", following the silly fashion adopted by some

takes its name from, not its first discoverer who was Montaigne in 1772, nor its second discoverer Pons in 1805, but from its third discoverer Biela in 1826. Then again, the comet universally called "Encke's" takes its name from a man who possibly never saw it at all[e] until after the time when his name had become permanently attached to it. But he dedicated so vast an amount of time and labour to an examination of its orbit that astronomers with one consent coupled his name to it. Nowadays it is usual to identify comets first of all temporarily by an italic letter of the alphabet joined to the year of discovery, and then afterwards by an ordinal number which indicates the order of the date of its perihelion passage amongst the comets of a particular year. Thus, Morehouse's Comet was first of all "Comet *c* of 1908", but it is permanently enrolled as the 4th Comet of 1908, usually printed as "Comet iv. 1908", or "the Comet of 1908 (iv.)".

A word of caution is perhaps desirable in connection with the system now in vogue of numbering the comets of a year. It was a long time before the system became settled, and previous to that being the case things were in great confusion; and the old confusion is even now operative to lead astray persons hunting up old comets in the indexes to Scientific Publications prior to 1872. It seemed very obvious to number the comets of a year in succession according to the dates of their discovery from January to December, but this presupposed that they passed perihelion in the same chronological order in which they were discovered. This, however, would be by no means always the case, so that, for instance, the 3rd comet in the order of discovery might prove to be the 2nd in the order of perihelion passage; and it might during the

of the London Hotels; so that if you are writing to a friend at the large Hotel in Russell Square you are expected to call it "Hotel Russell", in which case the postal address should be "Square Russell", which shows the absurdity of the whole thing.

[e] Encke's Comet was first discovered in 1786 by Méchain at Paris; it was rediscovered in 1795 by Miss Caroline Herschel; it was again rediscovered in 1805 by Thulis at Marseilles, and for the third time rediscovered in 1818 by Pons at Marseilles, so that Encke's connection with it came quite late in the day, yet nobody ever challenged, so far as I know, the attachment of his name.

year get into the periodicals as Comet No. 3 of a year, but would have to have its number altered subsequently during the year and have become No. 2 when the index was compiled. As comet discoveries multiplied the confusion became intolerable; hence the system now in vogue of letters of the alphabet as provisional designations, not to be replaced by numbers until a sufficient time has elapsed to make it certain that no disturbance of the order of perihelion passage could reasonably be anticipated. The credit of settling the present system on its existing basis is due to Dr. C. A. F. Peters, the editor of the German Periodical, *Astronomische Nachrichten*, expanding in 1872 a system suggested by the German Astronomical Society (The "Astronomische Gesellschaft") in 1867, but which missed its mark because it took no account of the order of discoveries being very often different from the order of perihelion passage.[f] It remains to be seen whether photography will give cause to the creation of fresh confusion arising from the fact that a photograph plate will "take" a comet and the plate may remain (as has happened) unexamined, and the existence thereon of a comet unknown, for weeks, or it may be for months, after the photographer has performed his share of the work.

An attempt was made some years ago to introduce the use of a couplet of names in the case of a comet proved to be periodic by reason of its making a second visit to us. Thus, the comet found in 1812 by Pons, was rediscovered in Sept. 1883 by Brooks. When the identity of the Comet of Sept. 1883 (which is now enrolled as 1884, i.) with that of 1812 became certain, it was called by American writers the "Pons-Brooks Comet", but the practice has happily not spread, and is not commendable. The awkwardness of it is shown in the following cryptogram: The "Tempel (3)-Swift" Comet, which means the third of the periodical comets discovered by Tempel, which was afterwards rediscovered by Swift and taken to be a new comet.

It has already been stated that the identification of a new

[f] For the details of the controversy see *Ast. Nach.*, vol. lxxviii, Nos. 1869, 1871, 1872. Nov. 1871—Jan. 1872.

comet can only be determined with any certainty when the "elements" of its orbit have been ascertained, and that the question of elements is of sufficient importance to need a separate chapter. But without forestalling what will be said there something more may conveniently be said here in dealing with the discovery of comets.

When a comet has been found it must be confessed that astronomers are always in a little flutter pending the inquiry whether the new comet is really a new one, or one that has been seen before, showing itself again to our ken for the second or third time. When the 3 observations necessary for determining its orbit have been made the computers set to work at once to see what is the size and shape and position of its orbit. These facts being ascertained resort is had to a catalogue of previous comets, which is searched in order to see whether the elements of the new comet's orbit bear any resemblance to those of any old comet. If any striking resemblance should be noticed between the longitude of the perihelion, the longitude of the ascending node, the inclination and the perihelion distance of the new comet and of any old comet, there is a *primâ facie* probability that the new comet is really the old one come again. Accordingly, further observations, prolonged through several weeks, are anxiously awaited in order to see whether they yield results which tally with the first provisional orbit. If they do, so much the better. If there is evidence to show that the new body is moving in an elliptic orbit, that is to say in an orbit which enables the comet to go round and round the Sun, then it becomes possible to assign a period for the comet's revolution round the Sun. This done, the question of identity with some comet already seen becomes very interesting. To quote a medical phrase, "an acute crisis" has been reached; but it is not safe at this stage to jump at conclusions as to identification because both the old and the new comets may have been subjected to disturbances of their orbits (called technically "perturbations") which may have considerably, or even completely, changed the shape and character of either or both orbits.

Very little stress can ever be laid on the personal appearance of 2 comets because, whilst many of them resemble one another very closely, the same comet at different epochs has often been known to present very different appearances. Reliance must not in all cases be placed on an apparent similarity of elements even where similarity to a striking degree seems to exist.[g]

When a new comet has been found it is a matter of the greatest importance to determine very accurately its position in the heavens from day to day; and this is sometimes not very easy, especially when the comet is viewed in twilight. But whatever may be its place, that is determined by measuring, by means of a micrometer, its angular distance from particular stars, whose exact position in Right Ascension and Declination is either accurately known, or can be ascertained at leisure. The stars used for this purpose are spoken of as "comparison stars". Ordinarily an equatorial has to be made use of, and its circles should of course be in very accurate adjustment. If, however, by good fortune the comet can be caught on the meridian and seen through a meridian instrument, the resulting places will usually be more accurate than if an equatorial is employed. Only 3 perfect observations are necessary for determining the general nature of a comet's orbit; but at best the first result will only be provisional, especially if the intervals between the observations are short, such as 2 or 3 days. Such observations will only yield an orbit in the form of a provisional parabola. If by any chance the comet is moving in an elliptic orbit, the intervals must amount to 2 or 3 weeks at the least for the character of the ellipse to be ascertained with any reasonable accuracy. The *plane of the orbit* and the comet's *perihelion distance*, ascertained provisionally, will not generally be varied much by the utilisation of subsequent observations; but it is another matter to determine accurately the *eccentricity* of the orbit, the dimensions of the *major axis*, and the corresponding *period*. The more the observations are prolonged the more the figures for these three elements will vary from those first

[g] See p. 18 (*ante*).

obtained; and of course the longer the interval of time on which they are based the more trustworthy the figures will become. The reason why the exact character of a comet's orbit is often very uncertain is that we on the Earth only see a comet when it is more or less near the Sun, near, that is, the focus of the orbit: and the shape of an orbit, whether really elliptic, parabolic or hyperbolic, differs very little at, and immediately on either side of, the perihelion point or point of

Fig. 29.

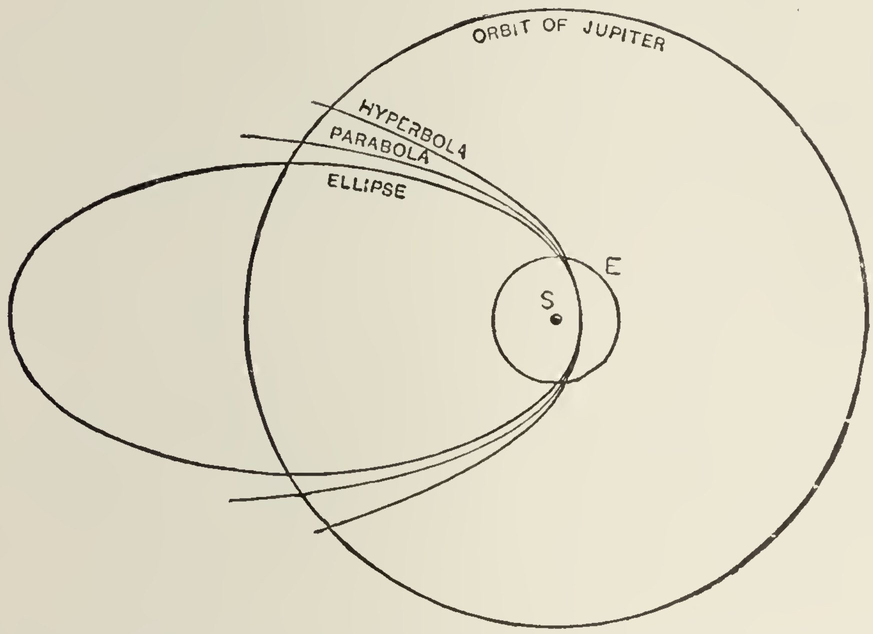


DIAGRAM SHOWING THAT WHEN A COMET IS NEAR PERIHELION AN ELLIPSE, PARABOLA AND HYPERBOLA DIFFER VERY LITTLE IN PLAN.

nearest approach to the Sun, as may be inferred by an inspection of Fig. 29.

Recently photography has come to play some part in the work of comet-hunting,[h] and it may here be mentioned that the Comet of 1892 (v.), discovered by Barnard on Oct. 12, was the first discovery which was due to a comet having recorded itself on a photographic plate arranged for stellar survey. He exposed a plate for a certain time, directed to the neighbourhood of *α* Aquilæ. On developing the plate a trail,

[h] Special photographic lenses may be had which permit of a large field of view being embraced; but a good driving clock for the telescope is essential as, owing to their faintness, comets need a long exposure before they will reveal themselves.

conjectured to have been impressed by a comet, was observable, and a few days later was easily picked up with a telescope. Though the comet had no particular interest in itself, its orbit soon attracted notice because it was seen to resemble very closely the orbit of Wolf's Comet, and Schulhof pointed out the extreme probability of the 2 bodies being two portions of one original—a case of Biela over again. It may be added that a good photograph generally discloses much more detail in a comet than can be recognised by the eye with a telescope.

Barnard's Comet of 1892 (v.) does not stand alone as an instance of astronomers having been assisted in their labours by the photographic art. After their discovery in the usual way it was found that several recent comets had impressed themselves on photographic plates long before their discovery visually. Thus Brooks's Comet of 1904 (i.) was photographed in May 1903, giving an interval thus covered by observation of 753 days. Again, Kopff's Comet of 1905 (iv.) was found on a plate exposed on Jan. 10, 1904, 783 days before its visual discovery, so that its period of visibility thus regarded might be said to have been more than 3½ years. Such records are of great value in tracing the movements of a comet because, thanks to the perfection which has been attained in celestial photography, photographic plates can be read and brought into line with the stellar co-ordinates of Right Ascension and Declination as effectively as if the services of a meridian instrument had been available for fixing the place of the comet at a given time on a given day.

So many of our observations of ancient comets (and those observations by far the most valuable) depend on Chinese records and descriptions of them that it may interest the reader to see how an ancient Chinese astronomer sought to convey his information to posterity. The following is Ma-tuan-liu's account of Halley's Comet in 837:—

"In the 2nd year of the Epoch Kae Ching, the 2nd Moon, day Ping Woo, there was comet in S. D. Wei. It was about 7 cubits in length. It pointed towards Nan Tow. On the day Woo Shin it was to the south-west of S. D. Wei. It was bright, and moved rapidly. On the day Kwei Chow its place was in S. D. Heu. On the day Sin Yew its length was about 10 cubits. It went to the west, gradually pointing to the South. On the day Jin Seuh

its place was in Woo Neu: its length was about 20 cubits, and was 3 cubits in breadth. On the day Kwei Hae the tail was still broad. In the 3rd Moon, day Kea Tsze, its place was in Nan Tow. On the day Yih Chow its length was 50 cubits, the end [of the tail] being divided into two branches, the one pointing to S. D. Te, the other covering S. D. Fang. On the day Ping Yin its length was 6 cubits, and was no longer branched. It pointed to the North. Its place was in the 7th degree of S. D. Kang. On the day Ting Maou it went to the North-west, pointing to the East. On the day Ke Sze its length was about 80 cubits: its place was then in S. D. Chang. On the day Kwei Wei it was but 3 cubits in length: its place was to the right of Heen Yuen. After this it was no longer visible."

In the foregoing extract "S. D." stands for "Sidereal Division". The Chinese divided the whole ecliptic into 28 Sidereal Divisions, equivalent, in a sense, to our 12 Signs of the Zodiac. For the fullest possible information on these matters the reader is referred to the work mentioned in the footnote.[i]

Twice it has happened that the search for comets has been stimulated by the promise of a distribution of loaves and fishes, if the metaphor may be permitted in a solemn scientific book. In the year 1835 the King of Denmark of the period, Frederick VI., instituted a gold medal to be given to the discoverers of telescopic comets, and several such medals were awarded.[k] Amongst the recipients the only English name we find is that of J. R. Hind. The grant of this medal was continued after the King's death in 1839 by his successor Christian VIII., but it was discontinued after the death of the last-named king in 1848. The Vienna Academy of Sciences formerly gave a gold medal to the discoverer of every new comet. This was discontinued about 1880. Mr. H. H. Warner, an American, then offered 200 dollars for every unexpected comet found in the United States or Canada. This was given up after a time, and then, after an interval, the idea was revived again by a wealthy American, Mr. J. A. Donohoe, in the year 1890, and a bronze medal is now regularly presented

[i] *Observations of Comets from* B.C. 611, *to* A.D. 1640, *extracted from the Chinese Annals. Translated, with introductory remarks.* By John Williams, F.S.A. 4to. London, 1871.

[k] *Ast. Nach.*, vol. xvii, No. 400, May 14, 1840; *Month. Not. R.A.S.*, vol. vi, p. 86, June 1844.

to the discoverer of any unexpected comet on the report of a Committee of the Astronomical Society of the Pacific.

In 1900 a German gentleman named A. F. Lindemann, living at Sidmouth, placed at the disposal of the German Astronomische Gesellschaft a fund to encourage the computation of cometary orbits. The sum of £5 (in marks) is paid for each definitive orbit whether of a modern or an ancient comet. This example deserves to be followed!

An interesting example of the way in which science has been promoted in America by the introduction into scientific fields of American commercial methods has been neatly sketched by Professor H. H. Turner, of Oxford. The Board of Visitors of the Observatory at Albany, doubting the value of some desk work (that is, non-telescopic work) which their Director was carrying on, "inquired tentatively whether it would not rather add to the reputation of the Observatory if some discovery, such as that of a comet, could be made; and were promptly informed that nothing was easier if they would sanction the devotion of a certain sum of money to the purpose, as salary for a person of average intelligence while making the necessary search. The challenge was accepted on the spot; the money subscribed; the searcher set to work, and within the allotted time a fine comet was found. Professor Boss undoubtedly took a certain risk in undertaking to catch a comet, just as a man would who undertook to catch a fish within a definite time. But he was anxious to vindicate his views of the relative importance of different kinds of work, and deserved the success he ventured to count upon".[l]

American astronomers have shown their national acuteness and labour-saving cleverness even in their way of transacting comet business. Some years ago they instituted a Comet Telegraph Code for transmitting, with a certain amount of detail, but in very concise visible form, information as to the discovery of new comets.[m] A specimen of a message in this

[l] *Lecture on Halley's Comet to the British Association*, 1908, p. 10.

[m] *Publications of the Astronomical Society of the Pacific*, vol. viii, pp. 109, 179, May, June, 1896; *Astronomical Journal*, Boston, U.S., vol. vii, p. 189, March 23, 1888.

code (known as the *Science Observer* Code) may be given as follows:—

"*Butler*	*Bun-alist*
Barnard	*Dar-ation*
Nashville	*Duz-ogoon*
Rol	*Baf-ofant*
October	*Baf-ôlute*
Kan-upate	*Beetle.*"
Boz-odate	

Which means:—"A faint comet was discovered by Barnard at Nashville on October 14. Its position October 15, at $9^h\ 30^m\ 15^s$ is R.A. $2^h\ 27^m\ 13.5^s$. N.P.D. 27° 13′ 23″. Its daily motion in R.A. is (-72^s), and in N.P.D. $(-8')$."

The advantage of a code is obvious, and the rules for working this one seem sufficiently clear to obviate serious mistakes in telegraphing. The head quarters of the movement is at the Harvard College Observatory, Cambridge, Massachusetts.

The code in use in Europe is on a different basis, and suits the difference in the European telegraph charges as compared with the American charges, and on the whole is more simple and more comprehensive. The head quarters of the European Use is the German Observatory at Kiel. The following is a sample message:—

"Comète Pechüle 16 Décembre 06500 Copenhague 28215 07929 36129 35745 14518 brillante, circulaire, condensation. Pechüle."

Which means:—"Une comète a été découverte par Pechule:
Dec. 16 6^h 50.0 T.M. Copenhague
A.R. = 282° 15
N.P.D. = 79 29
Mouv. diurne en A.R.: + 1° 29′:
en N.P.D.: − 2° 15′
Comète brillante, circulaire avec condensation. PECHULE."

CHAPTER VI.[a]

PERIODIC COMETS OF SHORT PERIODS.

Periodic Comets conveniently divided into 3 classes.—Short-period Comets in two groups.—Comets in Group I.—Encke's Comet.—The supposed Resisting Medium in space.—Its supposed effect on Encke's Comet.—Brief summary of its History.—The Resisting Medium theory not generally accepted.—Remarkable Observations in 1871. — *Tempel's Second Periodical Comet* (1873, ii.). — *Winnecke's Comet.* — *Brorsen's Comet.* — *Tempel's First Periodical Comet* (1867, ii.). — *Tempel* (3)*-Swift's Comet.* — *Finlay's Comet.—D'Arrest's Comet.—Wolf's Comet.—Holmes's Comet.—Brooks's Second Periodical Comet* (1889, v.). —*Faye's Comet.—Tuttle's Comet.—Short-period Comets in Group II.—Barnard's First Periodical Comet* (1884, ii.).—*Brooks's First Periodical Comet* (1886, iv.).—*Barnard's Second Periodical Comet* (1891, iv.).—*Spitaler's Comet* (1890, vii.).—*Perrine's Comet* (1896, vii.).—*Kopff's Comet.—Giacobini's Second Periodical Comet* (1900, iii.).—*Swift's Second Periodical Comet* (1889, vi.).—*Borelly's Comet* (1905, ii.).—*Swift's First Periodical Comet* (1885, ii.).—*Denning's Second Periodical Comet* (1894, i.).—*Metcalf's Comet* (1906, vi.).—*Denning's First Periodical Comet* (1881, v.).—*Giacobini's First Periodical Comet* (1896, v.).

The comets which will be dealt with in this volume under the general designation "Periodic" may be conveniently divided into 3 main classes:—

(I.) Comets of Short Periods.
(II.) Comets revolving in about 75 years, more or less.
(III.) Comets of Long Periods.

The comets belonging, or supposed to belong, to Class I must be put into 3 groups:—

(i.) Recognised members of the Solar System returning regularly at stated intervals.

[a] If it should be suggested that an undue amount of space has been allotted in this work to the Short-period Comets I would answer that scarcely a year ever passes that some of them do not return to the Sun and therefore to visibility to us on the Earth: and that consequently they are available for furnishing many chances of study to the readers for whom this work is mainly intended, namely, amateurs.

(ii.) Recent discoveries believed to be periodic but whose orbits are not very certainly known.

(iii.) Discoveries of such old date that as the comets have not reappeared they must be given up as "lost".

FIRST GROUP. RECOGNISED REGULAR COMETS.

No.	Name of Comet.	Period : Years.	Last Observed Return.	Next Return.
1	Encke's	3·29	1908	1911
2	Tempel's Second (1873, ii.)	5·15	1904	1909
3	Tempel-Swift's (1869, iii. : 1880, v.)	5·53	1908	1914
4	Winnecke's	5·54	1898	1909
5	Brorsen's	5·58	1879	1912
6	Tempel's First (1867, ii.)	5·98	1879	1910
7	Finlay's	6·54	1906	1913
8	D'Arrest's	6·64	1897	1910
9	Wolf's	6·76	1898	1912
10	Holmes's	6·85	1906	1913
11	Brooks's Second (1889, v.)...	7·07	1903	1910
12	Faye's	7·44	1894	1911
13	Tuttle's (1858, i.	13·66	1899	1913

All the foregoing comets, except perhaps Brorsen's, may be regarded as assured members of the Solar System, and certain to be seen again, sooner or later.

(1.) Encke's Comet.

Comet No. 1 in the foregoing list is by far the most interesting of all, and therefore its history deserves to be given in some detail.

On Jan. 17, 1786, Méchain at Paris discovered a small telescopic comet near β Aquarii. On the following day he announced his discovery to Messier who, owing to bad weather, did not see it till the day after, on which night it was also observed by J. D. Cassini Jun. and by Méchain himself. It was tolerably large and well defined, and had a bright nucleus but no tail, and was not seen again.

On Nov. 7, 1795, Miss Caroline Herschel discovered a small comet, about 5′ in diameter, without a nucleus, but showing a slight central condensation of light. Olbers observed it on Nov. 21, but it was too faint to allow of the field being illuminated, and he was obliged to compare it with stars in the same parallel by noting the times of transit across the field of view. It was round, badly defined, and about 3′ in diameter. The orbit greatly perplexed the calculators, and Prosperin declared that no parabola would satisfy the observations.

On Oct. 19, 1805, Thulis at Marseilles discovered a small comet faintly visible to the naked eye. Huth stated that on the 20th it was very bright in the centre, though without a nucleus, and was 4′ or 5′ in diameter. On Nov. 1 a tail 3° long was visible. Several parabolic orbits were calculated, and an elliptic one by Encke to which a period of 12·12 yrs. was assigned.

On Nov. 26, 1818, Pons at Marseilles discovered a small and ill-defined telescopic comet. As it remained visible for nearly 7 weeks a fairly complete series of observations was obtained. Encke, finding that under no circumstances whatever would a parabolic orbit represent them, determined to investigate the elements rigorously according to the method of Gauss then but little practised. So doing, he found that the orbit was certainly an ellipse, with a period of no more than about 3½ years. On looking over a catalogue of the comets whose orbits had been calculated up to that time he was struck by the similarity which the elements obtained by him bore to those of the Comets of 1786 (i.), 1795 and 1805, and he was strongly impressed with the idea that all these 4 comets were really one and the same comet, especially as reckoning backwards from 1818 intervals of 3½ years, or multiples of that period, would nearly or quite coincide with the perihelion passages of the comets of 1805, 1795 and 1786 (i.). The question could only be settled positively and conclusively by calculating backwards the effects of planetary perturbation and the necessary calculations Encke was able to accomplish by an extraordinary effort in 6 weeks. The result

was that he was able to assure himself of the identity of the Comet of 1818 with the 3 comets just mentioned, and that between 1786 and 1818 it had passed through perihelion 7 times without being noticed. But Encke was not content to let the matter rest there so he proceeded to calculate the date of the comet's next return, and found himself justified in announcing that the comet would arrive at perihelion on May 24, 1822, after having been retarded about 9 days by Jupiter.

"So completely were these calculations fulfilled, that astronomers universally attached the name of 'Encke' to the Comet of 1819, not only as an acknowledgement of his diligence and success in the performance of some of the most intricate and laborious computations that occur in practical astronomy, but also to mark the epoch of the first detection of a comet of short period—one of no ordinary importance in this department of science."

It unfortunately happened that in 1822 the position of the comet in the heavens was such as to render it only visible in the Southern hemisphere. It was therefore systematically watched by only one observer, Rümker, who discovered it on June 2 at the private observatory of Sir T. M. Brisbane at Paramatta, N.S.W., and he was only able to follow it for 3 weeks. Rümker's observations were however so far valuable that, besides showing that the comet actually did come back, they furnished Encke with the means of predicting with greater certainty its next return which he found would occur on Sept. 16, 1825. On this occasion it was first seen on July 13 by Valz, but was discovered independently by other astronomers. Cacciatore of Palermo described it as being round, with a faint nebulosity, and about 1° 30′ in diameter.

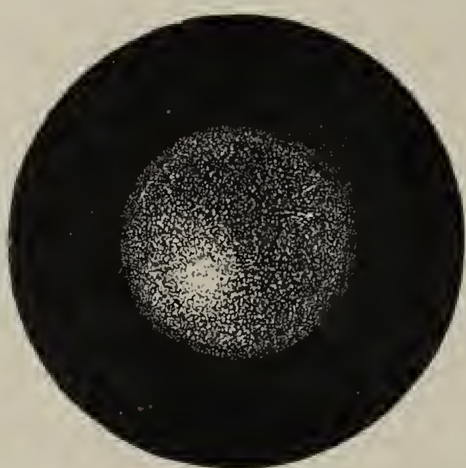
The next return to perihelion took place on Jan. 9, 1829. Struve at Dorpat found it on Oct. 13, 1828. Harding at Göttingen and Gambart at Marseilles both saw it for the first time on the same day, Oct. 27, the former having been on the look out for it since August 19. On Nov. 30 it was visible to the naked eye as a star of the 6th magnitude, and the week afterwards it had become as bright as a star of the 5th

magnitude. The outline of the coma was slightly oval with the minor axis (on one occasion at least) pointing towards the Sun.

The comet returned in 1832 but was only seen by one European observer, Harding at Göttingen, owing to its path lying chiefly in the Southern hemisphere.

Passing over the return of 1835, when the comet was seen both in Europe and at the Cape, we come to that of 1838. As the comet's apparent path would allow of observations being made in Europe under very favourable conditions it was looked for with much interest. Boguslawski discovered it on Aug. 14, but it was not generally seen till the middle of October. In the first week in November it was visible to the naked eye in Draco. With a telescope a rather bright nucleus was seen, and the general form of the coma was that of a broad parabola. It was this return which brought into prominence a peculiarity of the comet's motion which raised a question which still continues open for discussion. Encke found that, notwithstanding every allowance being made for planetary influences, the comet always attained its perihelion distance about $2\frac{1}{2}$ hours sooner than his calculations led him to expect. In order to account for this gradual diminution of the period of revolution, which in 1789 was nearly 1213^d, but in 1838 was scarcely $1211\frac{1}{10}^d$, Encke conjectured the existence of a thin ethereal medium, sufficiently dense to produce an effect on a body of such extreme tenuity as the comet in question, but incapable of exercising any sensible influence on the movements of the planets. Hind thus soliloquised on the subject:—"This contraction of the orbit must be continually progressing, if we suppose the existence of such a medium; and we are naturally led to inquire, What will be the final con-

Fig. 30.



ENCKE'S COMET: NOV. 30, 1828.
(*W. Struve.*)

sequence of this resistance? Though the catastrophe may be averted for many ages by the powerful attraction of the larger planets, especially Jupiter, will not the comet be at last precipitated on the Sun? The question is full of interest, though altogether open to conjecture." [b]

The following table, published by Encke,[c] will more clearly illustrate the changes in the comet's periodic time:—

Year of PP.	Period, Days.	Year of PP.	Period, Days.
1786	. .	1825	1211.55
(1789)	1212.79	1829	1211.44
(1792)	1212.67	1832	1211.32
1795	1212.55	1835	1211.22
(1799)	1212.44	1838	1211.11
(1802)	1212.33	1842	1210.98
1805	1212.22	1845	1210.88
(1809)	1212.10	1848	1210.77
(1812)	1212.00	1852	1210.65
(1815)	1211.89	1855	1210.55
1819	1211.78	1858	1210.44
1822	1211.66		

So far as it goes this table seems conclusive in its facts, but observations made at a return 10 years later than the last in the above table, namely in 1868, showed a *sudden diminution* in the retardation by nearly *one-half* the previously-noticed amount. And both the reality and also the permanence of this alteration were made clear in 1885. Some physical alteration in the comet has been suggested as the necessary explanation, but there is no visual evidence to lend colour to this idea.

The soundness of the explanation which assumes the existence of a Resisting Medium has been long and warmly canvassed, and it does not command the assent of astronomers generally. One strong point against it is that, with the exception *perhaps* of Winnecke's Comet (1858, ii.), none of the other short-period comets (all of them of small size and presumably slight mass) yield any indications of being subject to a like influence.[d] On the other hand Von Asten, who

[b] *The Comets*, p. 66.

[c] *Month. Not.*, vol. xix, p. 70. Dec. 1858.

[d] See a notice of a paper by A. Hall in *Month. Not.*, vol. xxxiii, p. 239. Feb. 1873.

worked at the problem very assiduously, thought there ought to be no hesitation in accepting the idea, subject to the limitation that the medium does not extend farther from the Sun than the orbit of Mercury.

The 1838 return is also noticeable for an important discovery in physical Astronomy which it indirectly was the cause of evolving. In August 1835 the comet passed very near the planet Mercury—so near in fact that Encke shewed that if Laplace's value of Mercury's mass was correct the planet's attractive power would diminish the comet's Geocentric R. A. on Nov. 2, 1838, by 58′, and increase its Declination by 17′. As the observations indicated no such disturbance of the comet's orbit it was obvious that the received mass of the planet was much too great, and as a matter of fact a much lower value has since been adopted.[e]

Passing over the returns of 1842 and 1845 as offering no points of particular interest we find that in 1848, on Sept. 24, the diameter of the comet's head was 8′ and that it was just visible to the naked eye on Oct. 6, and for some weeks subsequently. The adjacent illustration [Fig. 31, Plate IX.] will convey a good idea of the telescopic appearance of the comet during the month of September 1848. Early in November it had a tail about 1° long turned as usual *from* the Sun, and another and smaller one pointing *towards* the Sun. On Nov. 22 the comet was within 3,600,000 miles of Mercury.

Since 1848 Encke's Comet has been observed so many times that it would be monotonous and unprofitable to detail all the several appearances. I shall therefore only make a selection of apparitions which yielded some observations of interest and importance, more or less.

In 1871 the comet was well seen and numerous observations made. Some physical peculiarities were noted which deserve mention. In October, soon after its first discovery, the comet was a nearly round and faint nebulosity without apparent condensation anywhere. By the beginning of November it had

[e] In Hind's *Comets*, p. 65 *et seq.* the general principles upon which these inquiries are conducted are laid down with the clearness of language for which that distinguished astronomer was noted.

Fig. 31. *Plate* IX.

ENCKE'S COMET.

AS SEEN AT THE HARTWELL OBSERVATORY, SEPTEMBER 22, 1848.

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acquired a remarkable fan-like form, but the precise character of the exterior outline differed a good deal according to the power of the telescope employed.

Mr. Carpenter said [f]:—

"I was able to make out a considerable extension of the illumination beyond the bright fan-shaped condensation, but on one side (the spreading

Fig. 32.

ENCKE'S COMET: NOV. 9, 1871. (*J. Carpenter.*)

side) only. On the opposite side this diffused illumination appeared to be cut off nearly in a straight line immediately behind (following) the apex of the fan."

[f] *Month. Not.*, vol. xxxii, p. 26. Nov. 1871.

The Rev. H. C. Key, speaking in the first instance of what he saw on December 3, said [g]:—

"The train following the comet was quite broad in my telescope, and could not be termed a 'ray'. You will observe two rays on the preceding side; these I have drawn as you see, but I am not perfectly certain that the effect was not in my own eye and not a reality. I took every precaution to find out; and at the time (as well as now) felt pretty well convinced that it was no illusion. Four or five times I left the telescope, and upon returning there were the rays in exactly the same spot and direction. I feel pretty confident of their reality (they were extremely faint), but, as I say, am not quite certain, as I sometimes see dark lines in the field when first going to the telescope. The comet never seemed to me to lose its elliptical form from the first night I saw it, Oct. 20. I detected a nucleus for the first time on Nov. 7. The train I mentioned before was much fainter than the main body of the comet, and I was able to trace it to a distance of about 32′ from the nucleus. I saw nothing like the drawing of the comet made at Greenwich."

The return of 1871 was also important because it was found not to have been accelerated in accordance with the Resisting Medium theory as previous returns had been, since the first discovery of the comet in 1786. Von Asten's conjecture as to this is that in 1869 the comet might have come into collision with some minor planet which violently deranged and modified its orbit in some degree.[h]

Passing over the returns of 1875 and 1878 we come to that of 1881, in which year the comet passed through perihelion on Nov. 18. Common, using a 3-ft. reflector, noted the comet to be about 2′ in diameter, very faint even in an instrument of that size, and with slight indications of an increased brightness in the centre. Tacchini found the spectrum exhibiting bright bands in the yellow, green, and blue respectively, coinciding with the 3 principal bands seen in the spectra of the hydro-carbons. As in the case of some other comets, the bands were shaded off to the blue. A faint continuous spectrum was also detected.[i] The spectrum was considered to have undergone no change since the previous examination in 1878.

Since 1881 Encke's Comet has returned and been observed

[g] *Month. Not.*, vol. xxxii, p. 217. March 1872.

[h] *Bulletin de l'Acad. de St. Pétersbourg*, vol. v; *Observatory*, vol. i, p. 21, April 1877.

[i] *Comptes Rendus*, vol. xciii, p. 947.

in 1884, 1888, 1891, 1895, 1898, 1901, 1905, and 1908. It does not seem necessary to refer to these returns in detail unless it be to say that in 1895 (that is, at the end of 1894) and in 1898 the comet was very faint and observed with difficulty, whilst in 1904 it was found traced on a photographic plate as early as Sept. 11, though not generally seen till October and later months, when it was observed under very favourable circumstances at many Northern observatories. In 1908 it was not visually seen at all, but left a record of itself on a photographic plate. The only other remark which is worth making is, that comparing these recent returns as a whole it does not appear that the average brilliancy of the comet under average circumstances has varied much or at all during the 122 years that have elapsed since its first discovery. Berberich has written an interesting paper on the brightness of this comet at its many successive apparitions.[k] Perhaps it may be well to add that in 1888, 1898, and 1908 it was observed only or chiefly in the Southern hemisphere.

The period of Encke's comet is 3·315 years, so that it returns to the Sun 30 times in a century. The shortness of its period suggested to Miss Clerke that it might naturally be expected to *wear out* quickly, but there is not a tittle of evidence to justify this rash forecast.

(2.) Tempel's Second Periodical Comet (1873, ii.).

On July 3, 1873, Tempel at Milan discovered a faint comet fully 2′ in diameter, somewhat elongated in shape, with an eccentric condensation of light, and a granular appearance. When its orbit came to be calculated it soon became evident that the comet moved in an elliptic orbit with a period of rather more than 5 years. Hind pointed out that soon after passing its ascending node and when near aphelion the comet passes close to the orbit of Jupiter, to which fact is due its periodicity; and it is now to be regarded as, after Encke's, the comet which leads the group known as "Jupiter Comets".[l]

[k] *Ast. Nach.*, vol. cxix, No. 2836. Apr. 24, 1888.
[l] See p. 42 (*ante*).

Tempel's Comet returned again to perihelion in August 1878. It was seen at Oxford with difficulty in the 12-inch refractor of the University Observatory and resembled a faint round nebula 1′ in diameter with a very slight central condensation.

It was missed at its returns in 1883 and again in 1889, but it was seen in 1894 and 1899. In 1899 it was described as a fairly easy object in a 6-inch telescope; but it is thought to have become fainter at each return. A short diffused tail was noticed on a photographic plate. It was seen again during the winter of 1904–5.

(3.) THE TEMPEL(3)–SWIFT COMET.

On Oct. 10, 1880, Swift, at Rochester, New Jersey, U. S., found a small comet with a very diffused and ill-defined disc several minutes in diameter. It was soon ascertained that the orbit was elliptic with a period of about 6 years, and that the comet was identical with the Comet of 1869 (iii.) discovered by Tempel on Nov. 27, 1869. Hence astronomers designate this object by the very inconvenient title prefixed to this paragraph. The comet was very unfavourably circumstanced for observation at the return of 1874, and escaped detection, not only then but 12 years later, namely, in 1886. But at its next return in 1891 it was detected by Barnard on Sept. 27. Of no particular interest in itself, it may at least be said that its orbit is interesting in so far that when the comet returns to perihelion its position is such that it is alternately favourably and unfavourably placed for observation. Consequently its history thus far is as follows:—Seen in 1869 it was missed in 1875; seen in 1880 it was missed in 1886; seen in 1891 it was missed in 1897, when it passed through perihelion in June but was always at a great distance from the Earth. The above rule did not hold good in 1902 when the comet was due in January, and was not seen in that year; but it was seen again in 1908.

(4.) Winnecke's Comet.

A comet was discovered by Pons on June 12, 1819. Encke assigned to it a period of 5½ years, which, as the table shows, was a very close approximation to the truth. It was not, however, seen from that time till March 8, 1858, when it was detected by Winnecke at Bonn, and by him regarded as a new comet; but he soon ascertained the identity of the 2 objects. It must have returned in 1863 but was not then favourably placed for observation. The next return to perihelion occurred in June 1869. It was discovered by Winnecke himself on April 9 of that year, and is described by him as being faint, but as much as 6′ or 8′ in diameter. Some calculations by Oppolzer led him to think that this comet was observed previously to the occasion which has usually been regarded as its first discovery (namely, its detection by Pons in 1819) and that it is identical with the comet discovered by Pons in February 1808, which was only visible for 3 days and whose orbit was never calculated.

Visible again in 1875, but missed in the autumn of 1880, its next return was in 1886, when it was seen only in the Southern hemisphere after perihelion. It passed its perihelion 12 days earlier than it was predicted to do, and Oppolzer considered that its movements could not be completely explained by the theory of gravitation alone, but that the existence of some resisting medium was indicated: thereby confirming, according to the knowledge of 20 years ago, the theory then current as to the movements of Encke's Comet, spoken of on a previous page, but which theory has otherwise remained unconfirmed. This comet was observed in 1892 and 1898, but missed in 1904, in which year its perihelion passage was fixed for Jan. 21. Let us hope it may be seen 1909–10.

(5.) Brorsen's Comet.[m]

This comet was detected by Brorsen at Kiel on Feb. 26, 1846. The observations showed an elliptic orbit, and the

[m] A very interesting history of this comet by Kreutz, with additions by G. A. Hill, appears in *Astronomy and Astro-Physics*, vol. xi, p. 7. Jan. 1892.

epoch of the next perihelion passage was fixed for Sept. 26, 1851, but the comet's position then was not favourable owing to its proximity to the Sun, and it escaped observation. Bruhns re-discovered it on March 18, 1857. I remember to have seen it on March 23. It possessed the usual nebulous appearance of telescopic comets generally, and appeared to have a diameter of about 2′, though its position in the morning twilight probably marred its brilliancy. This comet again returned to perihelion in Oct. 1862 (not seen), in April 1868, in Oct. 1873, and in March 1879. The spectroscopic observations on the last-named occasion by Konkoly in Hungary and C. A. Young in America tended to show that the spectra of this comet and of Encke's Comet were identical with one another, and with a hydro-carbon spectrum. This comet escaped notice at its return in Sept. 1884, and was missed again in 1890, although favourably placed and sought for by powerful instruments. It was due to return to perihelion again in Aug. 1895 but was missed, and was again missed in 1900–1 and in 1906, so that it is not very clear whether we are entitled to recognize it as a permanent member of the Solar system. [See Fig. 36, Plate X.]

The period of Brorsen's Comet has been gradually diminishing owing to the effect of planetary perturbation.[n] Thus :—

In 1846 ;	period	= 2034	days.
In 1857 ;	„	= 2022	„
In 1868 ;	„	= 2002	„
In 1873 ;	„	= 1999	„
In 1879 ;	„	= 1994	„

and this diminution appears to have been going on ever since 1879.

The period being now 5·5 years, more or less, it results that the comet is alternately visible in spring and autumn, and the former apparitions are specially favourable for observations, because at this season, in consequence of the great inclination of the orbit, the comet reaches a high

[n] According to Axel Möller this is no question of a Resisting Medium.

Henry's (1873, v.).

Thatcher's (1861, i.).

Faye's (1873, vi.). Brorsen's (1873, v.).

Respighi (1863, v.).

VARIOUS TYPES OF COMETS.

(*Drawn by W. Tempel.*)

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northern declination. Another point which has been noted is that several weeks after perihelion the comet rapidly diminishes in brightness whilst its diameter increases considerably, even to 8′ or 10′ of arc.

According to D'Arrest the present orbit was due to the action of Jupiter in 1842, and according to W. E. Plummer serious disturbances from the same cause will happen in 1937, if the comet should last as long.[o]

(6.) Tempel's First Periodical Comet (1867, ii.).

On April 3, 1867, Tempel at Milan discovered a small comet. It had a nucleus eccentrically placed in an oval coma, and Talmage, on May 3, thought that the nucleus appeared to have a division across its centre. The comet remained visible for about 4 months, which enabled its orbit to be ascertained to be without doubt an ellipse of short period, which Searle fixed at 2064 days and Bruhns at 2074 days. It returned to perihelion in 1873 and was found by Stéphan at Marseilles on April 3. It was due to return to perihelion in May 1879, in Sept. 1885, in March 1892, in Oct. 1898, and in April 1905, and not having been seen in any of those years, perhaps it ought to be regarded as lost. Gautier found that the period of the comet, which was at first supposed to be about 6 years, had by 1885 been increased by no less than 5 months owing to the influence of Jupiter on its orbit.

(7.) Finlay's Comet.

On Sept. 26, 1886, Finlay, at the Royal Observatory, Cape of Good Hope, discovered a small tailless comet, 1′ in diameter. It was at first thought that it might possibly be identical with the lost Comet of Di Vico, but subsequent investigation disproved this idea; this comet is, however, now to be regarded as a recognised member of our system. It was re-discovered on May 17, 1893, shining like a star of the 11th mag. and still without a tail. It was missed in the winter of 1899–1900

[o] *Nature*, vol. xxx, p. 301. July 24, 1884.

owing to its being close to the Sun, coupled with its intrinsic faintness. It again returned to perihelion in 1906, being discovered by Kopff, and passing perihelion early in September. Owing to its being missed in 1900 some uncertainty existed as to its probable path in 1906, and its discovery in that year was very fortunate, for in 1910 it will approach so close to Jupiter as to be seriously affected by that planet. To this it may be added, that it is thought that its proximity to Jupiter in the year named will afford an opportunity for obtaining a new value for the mass of that planet.

(8.) D'ARREST'S COMET.

On June 27, 1851, D'Arrest, at Leipzig, discovered a faint telescopic comet in Pisces. Within a fortnight of its discovery the observations of its path through the heavens were found to be irreconcilable with a parabolic orbit; and the ellipticity of the orbit was soon placed beyond a doubt. Though the comet was visible for more than 3 months, the calculations of the orbit yielded very discordant results, and the successful prediction of the comet's return in the winter of 1857–8 must be regarded as something in the nature of a successful guess. Sir T. Maclear, at the Royal Observatory, Cape of Good Hope, was the only observer of the comet at this apparition.

Villarceau communicated to the Academy of Sciences at Paris on July 22, 1861, a memoir on the orbit of this comet which may be usefully placed on record here (in an epitomised form) as it will give some insight into the nature of the mathematical investigations which the calculaters of cometary orbits are called upon to conduct.

The perturbations experienced by this comet are owing chiefly to the action of Jupiter, to which it is so near, that during the month of April of the present year [1861] its distance was only 0·36, or little more than *one-third* of the Earth's distance from the Sun. Before and after this epoch, Jupiter and the comet have continued, and will continue, so little distant from one another, as to produce the great perturbations to which the comet is at present subject.

From a table of the elements of the perturbations produced by Jupiter, Saturn, and Mars, in the interval between the appearance of the comet in

1857–8 and its return to its perihelion in 1864, M. Villarceau obtained the following results :—

(1) The longitude of the perihelion will have diminished 4° 35′ to Aug. 1863, and will remain sensibly stationary for about a year from that epoch. (2) The longitude of the node will have continually diminished to the amount of 2° 8′. (3) The inclination will have increased 1° 49′ to the middle of 1862, and will diminish 6′ during a year, continuing stationary during the year following. (4) The eccentricity, after having increased to the middle of 1860, will diminish rather quickly, and will remain stationary from 1863–5 to 1864–6. "But of all these perturbations," says M. Villarceau, "the most considerable are those of the mean motion and the mean anomaly. After having increased from 5″ to July 1860 the mean motion diminishes 9″ in one year, and nearly 12″ in the year following, remaining stationary in the last year, and with a value 15″, 5″ less than at its origin. The perturbations of the mean anomaly, after having gradually increased till 1860, will increase rapidly till 1861, when they will amount to 10° 28′; and setting out from this, they will increase 9′, and in 1863 and 1864 they will have resumed the same value which they had in 1861."

The effect of the first of these perturbations will be to increase the time of the comet's revolution by about 69 days; and of the second, to hasten by 49 days the return of the comet to its perihelion in 1864. It will pass its perihelion on Feb. 26, whereas without the influence of these perturbations it would have passed it on April 15.

As was anticipated, the comet escaped notice at its return to perihelion in 1864, being unfavourably placed. But in 1870 it was found and followed for 4 months. In dealing with the observations of this return Winnecke pointed out that D'Arrest's Comet was undoubtedly the faintest of the known periodic comets, but probably that remark is no longer true. The comet was seen also in 1877, missed in 1884, and seen again in 1890, but its great southern declination limited the observations. Its light was reported to be feeble, and observations difficult even with large telescopes. Inasmuch as at its return in 1897 Perrine, at the Lick Observatory, saw the comet in a $3\frac{1}{4}$-inch Finder it seems almost certain that Winnecke's remark just quoted no longer holds good. In 1903 the comet was very unfavourably placed and was not seen.

(9.) Wolf's Comet.

The history of the first discovery of this comet presents some novel points of interest. In the ordinary course of narrative we should say that Wolf, at Heidelberg on Sept. 17,

1884, discovered a small telescopic comet which was described by Tupman, a week later, as about 2′ in diameter and possessing a stellar nucleus 3″ in diameter; but it appears that Copeland, at Dunecht, found it by means of the spectroscope, independently, on Sept. 22, 1884.[p] At its next return this comet was probably first seen at Vienna by Spitaler on May 1, 1891, and certainly by Barnard at the Lick Observatory on May 3. Under the influence of Jupiter the orbit of this comet suffered a complete transformation in 1875, and we may now regard it as permanently attached to our system, for at its return in 1898 the error of the ephemeris of its movements computed beforehand was only 1″ in R.A. and 4″ in Declination. It was not seen in 1905, being unfavourably placed.

(10.) HOLMES'S COMET.

On Nov. 6, 1892, E. Holmes, at Islington, discovered a bright comet in Andromeda, which was also discovered independently on Nov. 9 by Davidson in Queensland. The comet was described by Holmes as 5′ in diameter, and bright enough to be seen by the naked eye. The greatest theoretical brilliancy should have occurred in September, when the comet should have been rather brighter than on Nov. 6, and was well situated for observation in the Northern hemisphere. It is therefore remarkable that it should not have been detected sooner, but the explanation is no doubt to be found in the fact that the comet underwent great fluctuations of brilliancy during the time it was visible in the winter of 1892–3.

The most complete and interesting account of Holmes's Comet which we have is due to E. E. Barnard, whose observations and remarks [q] will now be given in a compressed form:—

"From several points of view it was one of the most remarkable comets ever observed.

At the time of discovery it was distinctly visible to the naked eye as a slightly ill-defined star of the 6th magnitude. The remarkable fact that

[p] *Sid. Mess.*, vol. x, p. 288. June 1891. This would seem to be the only comet ever discovered by means of a spectroscope.

[q] *Astrophysical Journal*, vol. iii, p. 41. January 1896.

Fig. 38. *Plate* XI.

HOLMES'S COMET, NOVEMBER 10, 1892, AND THE NEBULA 31 M. ANDROMEDÆ.

(*Photographed by E. E. Barnard.*)

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the comet had attained naked-eye visibility when discovered, coupled with the further fact that this region must have been repeatedly swept over by comet-seekers to within a few days of the discovery, shows that the comet must have rather suddenly attained its conspicuous visibility. When found this object was already some five months past perihelion, and had been theoretically for several months in a far better condition for discovery. From the care and skill shown by the large number of astronomers now engaged in comet-seeking, there can be no doubt whatever but that this comet did not exist during that time with anything like one-tenth of the brightness it had at discovery.

From this, and its subsequent remarkable behaviour, several astronomers argued that the object was not a comet in the true sense of the word, and that it must be the product of some celestial accident. This idea was further strengthened when its orbit was computed, and was found to lie within the asteroid zone. This orbit differed altogether from that of the ordinary comet by being almost circular. According to the orbit the comet ought to have been easily visible at every previous opposition and should have been discovered long ago.

It seemed highly probable at least that it should be seen at its next opposition when it would be very favourably placed for observing. Though carefully searched for, no trace of the comet could be seen with the 12-inch and the 36-inch of the Lick Observatory.

From the fact that the orbit lay out among the asteroids Corrigan and Kirkwood suggested that possibly two asteroids had collided and produced the phenomenon of a comet. However much faith may be placed in this hypothesis, I think, from the peculiar phenomena witnessed during the visibility of the comet, that it does not now exist in the cometary form, and furthermore, I do not think that it will ever be seen again, though it should return to perihelion in 1899. All the circumstances connected with it rather tend to show that it was of only a temporary nature.

The announcement of the discovery of this comet was received at the Lick Observatory on November 8, 1892, and it was observed that night with the 12-inch refractor. Its appearance was absolutely different from that of any comet I had ever seen. It was a perfectly circular and clean cut disk of dense light, almost planetary in outline. There was a faint, hazy nucleus with a slight condensation some 5″ south following the nucleus. With the naked eye the comet was just as bright, exactly, as the brightest part of the Great Nebula of Andromeda, near which it was visible.

At $8^h\,0^m$ a careful estimate of its diameter made it 260″. At $9^h\,40^m$ careful micrometer measures made the north and south diameter 286″.

On November 9, at $6^h\,5^m$ the comet was brighter to the naked eye than the brightest part of the Andromeda nebula. At $6^h\,20^m$ the measured diameter was 337″ north and south, with the 12-inch telescope; there was a faint diffused glow 12′ in diameter surrounding the comet symmetrically and a short, faint diffusion south following. The nucleus preceded the centre about $\frac{1}{2}'$ while at the centre there was a slight condensation. With the naked eye at $8^h\,0^m$ the comet looked like a small star and almost equal in brightness to ν Andromeda, and could not be distinguished from a star. At $8^h\,30^m$ it was looked at with the 4-inch comet-seeker—the diffused haze could be seen surrounding it with faint traces of a tail."

After November 9 the comet gradually became fainter, and on November 16 Barnard found "nothing different in its appearance from the ordinary comet, except its size." It continued to grow fainter, and on January 4, 1893, "there was only the most excessively faint trace of the comet—a feeble glow extremely difficult to see." Barnard then goes on to say:—

"Bad weather interfered with observations until January 16, when it cleared at dark. It seemed scarcely possible that the comet could be seen again, but from the importance of any positions of it, I thought it worth trying once more. The 12-inch was set for it, and upon looking in the telescope I was surprised to see a small, bright, hazy star. Thinking some mistake had been made, the telescope was again set only to find the same object. It seemed impossible that this star-like object could be the excessively faint and diffused nebulosity previously seen. Observations for motion, however, soon showed that it was in reality the comet. . . . In the finder, however, it appeared perfectly stellar and could not possibly be distinguished from an 8th magnitude star. At $9^h 50^m$ the mean of two measures gave $32''.4$ for the diameter. At this time there had begun to appear in the condensation a small nucleus which had not been visible at first. It seemed to brighten rapidly while being watched, and soon became very distinct. At $10^h 20^m$ there was no question but that the nucleus was brightening; it seemed to form and become clear and distinct right before one's eyes.

At $10^h 30^m$ the 36-inch was turned upon the comet. It appeared very beautiful and remarkable in the great telescope. With this instrument its diameter was measured $= 44''$. In the great telescope it looked exactly as it did on November 8 when first seen with the 12-inch. It was pretty well terminated and had a pretty bright nucleus. A few minutes later another set of measures was made of its diameter $= 47''$.

The nebulosity was bluish, but the nucleus was hazy and yellowish and central. At $10^h 55^m$ there was a feeble glow about the comet, something like $1'$ in diameter. Further measures were made with the great telescope: at $11^h 13^m$ diameter $= 47''.3$. On this night there was no question whatever but that the nucleus actually formed in a few hours' time, while the comet was under observation; at the same time the body of the comet appeared to be expanding gradually."

During the next following nights the comet was watched gradually growing in size, and on—

"January 20, with the 36-inch at $6^h 45^m$ the measured diameter was $136''$. The nucleus was of the 10th magnitude and quite conspicuous, while the comet was much brighter in the middle. Taken altogether the object looked like a spherical mass of vapour, rounding up beautifully, with the nucleus shining in the middle.

January 22. With the 36-inch the comet was very diffused and was estimated to be $3'$ or $3'.5$ in diameter. At $7^h 30^m$ the nucleus was very indistinct and about 12th magnitude. There was a hazy glow close about the nucleus that seemed to partially hide it.

January 24. On the moonlit sky, the comet, in the 12-inch, appeared to be about 1′ in diameter—its greater portion being lost in the brightness of the sky. There was no nucleus. With the finder the comet appeared rather bright and cometary—like a large and conspicuous nebula. After this, absence from the Observatory prevented the comet from being followed further."

Photographs of the comet were made: the most interesting and important of these was the one made on November 10, but Barnard remarks:—

"That the central, well-defined body of the comet has been lost in the half-tone, the outline shown being that of the diffused haze surrounding the comet proper. The nebulous appendage, however, is fairly well shown. . . .

There is one other thing that this photograph shows (and which seems to have been generally overlooked) that must sometime be of the highest importance in the solution of the mystery surrounding this extraordinary object. To the south-east of the comet, distant about one degree or so, is shown a large irregular mass of nebulosity covering an area of one square degree or more, and noticeably connected with the comet by a short hazy tail. Evidences of this diffused nebulosity had been seen when examining the region about the comet with a low power on the 12-inch. This very extraordinary appendage deserves the earnest attention of those who are at all interested in this comet."

On Jan. 18, 1893, Palisa found the comet to shine as a star of the 8th mag. surrounded by a nebulosity no more than 20″ in diameter. The striking variations which this comet underwent would seem to explain the fact that it had remained undetected at previous apparitions, for it is now a recognised short-period comet fully entitled to a place on the regular list. It returned in 1899, passing through perihelion on April 13, and discovered by Perrine at the Lick Observatory on June 10, shining as a star of the 6th mag. It returned again in 1906, passing perihelion about the middle of March, but it was very faint, and seen only in some of the largest telescopes in the world. It has been thought that Holmes's Comet not improbably belongs to a family of which the lost Di Vico is a member. Its sudden outburst of brilliancy at the time of its first discovery in Nov. 1892 would seem to have been an incident in the comet's history without precedent, so far as we know, and one which has never been repeated. Holmes's Comet has the least eccentric orbit of any of the comets moving in elliptic

orbits, the eccentricity being 0·41; Tempel's First Periodical Comet comes next with an eccentricity of 0·46.

Fig. 38, Plate XI. is a representation of Holmes's Comet in the same field as the Great Nebula in Andromedæ (31 M.), enlarged from a photograph taken by E. E. Barnard on Nov. 10, 1892.

(11.) BROOKS'S SECOND PERIODICAL COMET (1889, v.).

The comet discovered by Brooks on July 6, 1889, is interesting both in itself and as regards its orbit. When first seen it was rather faint and had a short wide tail, and did not undergo any great change of appearance during the remainder of the month, but on Aug. 1 it was found to have thrown off fragments 4 in number. Two of these were very faint and soon disappeared, but the other 2 brighter ones were miniatures of the main body, each having a nucleus and a tail. For a while they moved away from their primary. In 3 weeks the nearer companion ceased to recede; it then expanded, and finally disappeared. The farther companion continued to recede until it had become (a month from discovery) brighter than the parent comet. In another month it began to approach its parent; its head swelling and becoming faint, the tail disappearing. Altogether, the history of these transformations is very curious.[r] The small inclination and direct motion noticed when its orbit was determined suggested that the comet was a periodical one, and this fact was soon established. The orbit at aphelion approaches very closely to that of Jupiter, and Chandler found that in 1886 the comet's distance from the planet did not exceed $\frac{1}{10}$th of the Earth's mean distance from the Sun, from which fact it has been assumed that the comet's orbit acquired its present ellipticity then and on that account: and that Jupiter or Jupiter's Satellites had had some share in fracturing the comet as above described.

This comet returned in 1896, and was found by Javelle at Nice on June 20, as a single comet, no companions or frag-

[r] *Ast. Nach.*, vol. cxxii, No. 2919, Aug. 29, 1889; *Ibid.*, No. 2922, Sept. 6, 1889.

ments being visible. But it is possible that this failure may have been due to the faintness of the nucleus at that apparition. The observations did not favour the probability of the comet being identical with Lexell's, as was first thought. In 1903 this comet was again in perihelion and was discovered by Aitken at Lick on Aug. 20. The greatest diameter was about 3′, and the brilliancy that of a 14th mag. star. The steady diminution in the brightness of this comet is so marked that it is hazardous to predict its future. At its last return in 1903 it was so much more faint than at its previous apparitions that it was only visible in some of our largest telescopes. It is due to return in 1910 and again in 1917. Shall we see it? Perhaps we shall: perhaps we shall not. But if we do see it on either of these 2 occasions it will still be leading a threatened life, for in 1921 it will again approach very close to Jupiter, and very likely that may end its career; or if not, it will certainly lead to a serious transformation of its orbit.

(12.) Faye's Comet.

After Encke's Comet, Faye's may be regarded as the best-known and most regular of the short-period comets. It was discovered by Faye at the Paris Observatory on Nov. 22, 1843, in the constellation Orion. It exhibited a bright nucleus with a short tail, but was never sufficiently brilliant to be seen by the naked eye. That the comet's path was an ellipse, and the comet itself therefore a periodical one, seems to have been soon suspected by several astronomers, but to Le Verrier is due the credit of having exhaustively investigated its orbit. He showed that the comet came into our system at least as far back as the year 1747, when it suffered much perturbation from Jupiter; and that its next perihelion passage would occur on April 3, 1851. It was rediscovered by Challis on Nov. 28, 1850. O. Struve described it under the date of Jan. 24, 1851, as having a diameter of 24″. During the whole of this apparition it scarcely exhibited any signs of nucleus or tail. Faye's Comet returned in due course, and was seen in 1858, 1866, 1873, 1880, 1888, and 1895, but it was missed in

1903, though it would have been interesting to have ascertained whether the influence of Jupiter had accelerated its return by 4 months, as Stromgren calculated would have been the case. The orbit of Faye's Comet is the least eccentric of all the short-period orbits. A sketch of Faye's Comet by Tempel will be found on Plate X.

(13.) TUTTLE'S COMET.

This comet was first seen by Méchain on Jan 9, 1790. It was only followed for a fortnight. On Jan. 11 Messier could see only a confused nebulosity without any indications of a nucleus. It was not reobserved until its return in 1858, on Jan. 4 of which year it was discovered by H. P. Tuttle at Harvard College Observatory, Cambridge, U.S., passing its perihelion on Feb. 23. It was found to be a periodical comet with a period of about 13½ years. It returned again to perihelion and was seen in Nov. 1871, August 1885, and May 1899. Its orbit has been thoroughly investigated by Rahts.

SECOND GROUP. COMETS PROBABLY PERIODIC.

No.	Name of Comet.	Period: Years.	Last Observed Return.	Next Expected Return.
1	Barnard's First (1884, ii.)...	5·5	1884	1911
2	Brooks's First (1886, iv.)	6·3	1886	1909
3	Barnard's Second (1891, iv.)	6·3	1891	1911
4	Spitaler's (1890, vii.)	6·3	1890	1910
5	Perrine's (1896, vii.)	6·4	1896	1910
6	Kopff's (1906, iv.)	6·6	1906	1913
7	Giacobini's Second (1900, iii.)	6·7	1900	1914
8	Swift's Second (1889, vi.)	7·0	1889	1910
9	Borelly's (1905, ii.)	7·0	1905	1912
10	Swift's First (1885, ii.)	7·2	1885	1913
11	Denning's Second (1894, i.)	7·4	1894	1909
12	Metcalf's (1906, vi.)	7·6	1906	1914
13	Denning's First (1881, v.)...	8·8	1881	1915
14	Giacobini's First (1896, v.)	7–9 ?	1896	?

The comets in this group are all recent discoveries, but as none of them have been seen more than once their claims to be regarded as permanently attached members of the solar system must be regarded as in suspense for the present.

(1.) Barnard's First Periodical Comet (1884, ii.).

On July 16, 1884, E. E. Barnard, at Nashville, Tennessee, U.S., using a 6-inch refractor, discovered a nebulous object which he thought had a suspicious appearance. Some days however elapsed ere its cometary character was ascertained beyond a doubt, by reason of it being found to be moving. Perrotin described it as exhibiting on Aug. 15, an ill-defined nebulosity about $1\frac{1}{2}'$ in diameter. The ellipticity of the orbit was soon ascertained. If Berberich's period of 5·49 years is correct the comet must have approached very near to Mars in April 1868, and have had its orbit interfered with by that planet.

This comet should have returned in 1889, but was missed in that year, and again also in June 1895. It was also missed in Oct. 1900, though about the time it was expected 25 photographs were taken over a range of sky covering the comet's expected position. Nor was it seen in 1906. Whether this comet should be transferred to the list of "lost" comets remains for future consideration.

(2.) Brooks's First Periodical Comet (1886, iv.).

This comet was discovered by Brooks on May 22, 1886. It passed its perihelion on June 6. A period of 6·3 years was assigned to it. It was not seen when expected in 1892, 1899, and 1903, and therefore its continued existence must be regarded as an unknown quantity. We must see what the years 1909 and 1910 bring forth.

(3.) Barnard's Second Periodical Comet (1891, iv.).

The circumstances under which this comet was discovered by means of a photograph on Oct. 12, 1892, have already been mentioned. Suffice it to say here that a period of

6·3 years was assigned to it. It was expected to return in April 1898, but was not seen, the position in the heavens being unfavourable; nor was it seen in 1905, when again expected to have been in perihelion.

(4.) SPITALER'S COMET (1890, vii.).

Whilst searching for Zona's Comet, which had been discovered at Palermo on Nov. 15, 1890, Spitaler of Vienna detected a faint nebulous object near the reported place of Zona's Comet.[s] This turned out to be a new comet, and though the observations were somewhat limited the ellipticity of its orbit was quite free from doubt, and a period of about $6\frac{1}{2}$ years or less was assigned to it. It was thought that the comet had only recently entered the Solar System, because in 1887 at its descending node it approached so closely to Jupiter that its orbit must have been seriously affected. The comet was calculated to be due to appear again in March 1897, but it escaped detection, and as the same thing happened in 1903 it must be regarded, at any rate for the present, as lost.

(5.) PERRINE'S COMET (1896, vii.).

On Dec. 8, 1896, Perrine at the Lick Observatory discovered a small comet which was found to be moving in an elliptic orbit with a period of 6·44 years. It should have returned in 1903 and have passed through perihelion in April, and perhaps did so, but it escaped notice. This was, however, not to be wondered at, because not only was it near the Sun, but its estimated brightness was only $\frac{1}{16}$th of what it was when the comet was seen for the last time in 1897.

(6.) KOPFF'S COMET (1906, iv.).

On Aug. 26, 1906, Kopff at Heidelberg discovered a small comet which was found to be revolving in an elliptic orbit with a period of about $6\frac{2}{3}$ years.

[s] Barnard pointed out the "remarkable coincidence" of 2 comets totally unconnected with each other being visible at the same time within 1° of each other, as a thing which had never happened before, and was never likely to happen again. (*Sidereal Messenger*, vol. x, p. 18. Jan. 1891.)

(7.) Giacobini's Second Periodical Comet (1900, iii.).

On Dec. 20, 1900, Giacobini at Nice discovered a small comet which was found to be moving in an elliptic orbit with a period of about $6\frac{3}{4}$ years. The elements bear a considerable resemblance to those of the comets of Wolf and Barnard (1892, v.). The comet had passed its perihelion when discovered, and its increasing faintness, and unfavourable position in the sky, rendered observation of it very difficult towards the end of the 8 weeks during which it was in view. It was not seen at its expected return in 1907, so we shall have no chance of knowing anything more about it until 1914.

(8.) Swift's Second Periodical Comet (1889, vi.).

This comet, discovered by L. Swift on Nov. 16, 1889, presented the ordinary appearance of a telescopic comet without pronounced nucleus or tail. The ellipticity of its orbit soon became evident, and a period of about 7 years was assigned to it. It ought to have returned in 1898 but escaped notice; and we can only say now that as the character of its orbit is so very uncertain no forecast of its future career is possible.

(9.) Borelly's Comet (1905, ii.).

On Dec. 28, 1904, Borelly at Marseilles discovered a small comet which remained visible for 5 months. Its orbit was found to be elliptic, with a period of about 7 years. It has been suggested that this comet was identical with the Comet of 1783 (i.), for which a period of 5·9 years was assigned by C. H. F. Peters. Its expected return in 1911, or 1912, will be awaited with interest.

(10.) Swift's First Periodical Comet (1885, ii.).

On Aug. 20, 1885, L. Swift detected a faint comet in Pisces which during its whole period of visibility of about 2 months was never very conspicuous. Observation soon showed that the comet was a periodical one, and a strong suspicion was

put forth that it was a reappearance of the long-lost comet of Lexell of 1770. Unfortunately the period and the position of the orbit are such that no return favourable for observation can be expected before 1931; and it is doubtful whether the observations of 1895 were sufficiently complete to enable the character of the orbit to be determined with precision. The period assigned by Schulhof is 7·19 years.

(11.) DENNING'S SECOND PERIODICAL COMET (1894, i.).

On March 26, 1894, Denning discovered in Leo Minor a faint comet which was becoming fainter because the perihelion passage had occurred as far back as Feb. 9, and the comet was receding both from the Sun and the Earth. That its orbit was elliptic, with a period of about 7½ years, was soon ascertained, but owing to the lack of an adequate number of observations definitive elements could not be assured. Schulhof called attention to the fact that the point of nearest approach between the orbits of the comet and Jupiter coincided very nearly with the point at which Brorsen's Comet and Jupiter were nearest one another. This fact was further emphasised by Hind, who showed that the two comets were actually very near one another 13 years previously, namely in April 1881.

This comet awaits further consideration before it can be regarded as a recognised short-period comet. Although expected to return in 1901 it was not seen in that year. Nor in 1909 thus far.

(12.) METCALF'S COMET (1906, vi.).

On Nov. 14, 1906, J. Metcalf at Taunton, Mass., U.S., discovered a very faint comet shining as a 12th mag. star. It proved to be revolving in an elliptic orbit with a period of rather more than 7½ years; and to be one of the Jupiter family of comets. Though the elements resemble those of the comets of Faye, Wolf, 1892 (v.), 1896 (v.), and 1900 (iii.), identity with any of these is not possible.

(13.) Denning's First Periodical Comet (1881, v.).

On Oct. 4, 1881, Denning at Bristol discovered a bright telescopic comet in the constellation Leo. It was circular in form, about 1′ in diameter with a slight central condensation. It soon became known that its orbit was elliptical, and its period about $8\frac{3}{4}$ years. It was expected to return in 1890 but was not found; the explanation perhaps being that the expected date of its perihelion passage indicated a path unfavourable for observation. As it could not be found in 1899 nor in 1907, in both of which years it was due to return to perihelion, and as its orbit could not be determined very accurately in 1881 for the lack of sufficient observations, this comet must for the present at least be set down as "lost".

The elements bear some resemblance to those of the Comet of 1819, discovered by Blainpain. Winnecke suggested that the comet seen by Goldschmidt at Paris in May 1855, and then regarded as perhaps Di Vico's, and Hind's Comet of 1846 (ix.), may both have been apparitions of Denning's Comet; but it can only be said of this suggestion that it is at best a plausible one.

(14.) Giacobini's First Periodical Comet (1896, v.).

Giacobini at Nice on Sept. 4, 1896, whilst searching for a faint comet discovered by Sperra on Aug. 31, detected a faint comet in Ophiuchus. It soon became evident that it was one of short period, but the early observations yielded very discordant results. In fact the first period obtained was only 17 months. The comet was not seen in 1903, when it was expected on the supposition that its period was 6·6 years, according to Ebell's calculation, but the Lick observations imply a period of 9 years.

CHAPTER VII.

LOST COMETS.

Lexell's Comet.—Its mysterious disappearance.—Efforts made to identify it with other Comets.—Biela's Comet.—Its division into 2 portions.—Its disappearance.—Di Vico's Comet.—Other supposed Short-period Comets which have never been seen a second time.—Grischau's Comet.—Helfenzrieda's Comet.—Pigott's Comet.—Blainpain's Comet.—Peters's Comet.—Coggia's Comet.

Thus far we have been considering comets which are either known for a certainty to be revolving in elliptic orbits, and which have themselves verified the fact by returning one or more times to our view, or comets, the ellipticity of whose orbits seems open to no doubt, but which have not yet fulfilled the predictions which have been made in respect of them. It now becomes necessary to speak of some comets, to 3 of which in particular an extraordinary amount of unsolved mystery attaches.

Lexell's Comet.

This comet has already been mentioned,[a] but something more needs to be said in regard to its claims to be considered a short-period comet.

Astronomers in the present day have to lament the "loss" of several comets which, at first, were regarded as assured members of the Solar System, because of the comparative smallness of their orbits, and the apparent certainty that their periods of revolution were under 10 years, but this loss is not unprecedented, and the comet which we have now to consider is not only the oldest, but in some senses the most notable instance which can be adduced of a "lost" comet.

On June 14, 1770, Messier at Paris discovered a fairly

[a] See pp. 17, 39, 79, 84 (*ante*).

bright comet with a stellar nucleus. On July 1 it had greatly increased in apparent size, and though no tail was visible the nebulosity surrounding the nucleus had swollen to a diameter $2\frac{1}{3}°$ or more than five times the diameter of the Moon—dimensions still remaining wholly unprecedented. The comet remained visible altogether for nearly 4 months, and disappeared from view owing to the increase of its distance from the Earth, it having become when last seen very small and faint. Various attempts were made by different astronomers, but unsuccessfully, to reconcile the observations with a parabolic orbit. Some years later Lexell, a member of the Academy of Sciences at St. Petersburg, investigated anew the orbit, which he found for a certainty to be elliptic; and that the comet's period was about $5\frac{1}{2}$ years. Supposing this had been correct the comet should have returned to perihelion in 1776, but it was not seen, though Messier and others were constantly on the watch for new comets generally.

Lexell's researches disclosed to him the fact that in May, 1767, the comet had passed very close to Jupiter, and had remained for a considerable time exposed to the influence of this planet. Lexell thought that this fact had exercised such a material effect on what had been the previous orbit of the comet as to transform that orbit into the short-period ellipse which he found represented the comet's movements in the year 1770. With the materials before him, Lexell put forth the suggestion that the comet ought to be seen again in the Summer of 1781, after again passing under the powerful influence of Jupiter in the Summer of 1779. Diligent, but unsuccessful, search was made for it at the time of its expected reappearance; and the conclusion drawn by Lexell was that as Jupiter in 1767 had driven the comet into its small elliptic orbit, so in 1779 the same planet had driven the comet out of its small elliptic orbit into a new one which could not be, and never has been, traced. It was because of the prolonged and comprehensive labours of Lexell on this comet that astronomers have always agreed to attach his name to it.

Nothing more was done in the matter until 1806 when Burckhardt, an eminent French Mathematician, traversed

anew the ground gone over by Lexell, and was able to confirm substantially Lexell's conclusions. This remark, however, more especially applies to what Lexell suggested as to the influence of Jupiter, but Burckhardt varied Lexell's conclusions by suggesting that after the comet escaped from the clutches of Jupiter in 1779, its orbit was enlarged to an ellipse with a period of more than 16 years, and with a perihelion distance so great that the comet would for ever be at so great a distance from the Earth that we could never hope to see it again.

After the lapse of nearly half a century the orbit of Lexell's Comet was again investigated, and this time by Le Verrier, in a paper presented to the Academy of Sciences at Paris, in May, 1848. Le Verrier's calculations in some respects support, and in others differ from those of his predecessors, but the questions involved would occupy more space than it is convenient to allot to them in these pages. Hind's summary of them is as follows:—"The final conclusion from Le Verrier's investigations is that the Comet of 1770 may be considered lost until it is accidentally rediscovered in the ordinary course of searching for these bodies, when his formulæ will enable the astronomer to recognise in the new comet that interesting wanderer."

These words were written in 1852, and persistent have been the efforts of astronomers to find in each new short-period comet the old Lexell, but the results thus far have been inconclusive. It remains to be added that Brünnow has confirmed in part Burckhardt's calculations.

When Lexell's Comet on July 1, 1770, was at its minimum distance of about $1\frac{1}{2}$ millions of miles from the Earth, the visible diameter of the comet was, as already stated, $2^\circ\ 23'$; it follows therefore that the true diameter was 60,000 miles.

Biela's Comet.

On March 8, 1772, Montaigne at Limoges discovered a comet which, from the want of suitable instruments, he was unable properly to observe, or to observe at all after March 20.

Messier, however, saw it 4 times between March 26 and April 3.

On Nov. 10, 1805, Pons discovered a comet which was also found by Bouvard on the 16th. It had a nucleus, and the diameter of the coma on Nov. 23 was 6′ or 7′. On Dec. 8 it was at its nearest to the Earth, and Olbers saw it without a telescope. Bessel and others calculated elliptic elements, and its identity with Montaigne's Comet was suspected, though no predictions as to when a return might be looked for again seem to have been ventured on.

On Feb. 27, 1826, an Austrian officer named Biela, at Josephstadt in Bohemia, discovered a faint comet which Gambart[b] found on March 9. The observations extended over a period of 8 weeks, and it was soon recognized that not only was the comet's orbit an ellipse of moderate eccentricity; but that it was the same comet as those observed in 1772 and 1805.

In anticipation of its next return in 1832, investigations into the orbit were undertaken by Santini, Damoiseau, and Olbers. Santini found that the comet's period in 1826 was 2455 days, but that the attraction of the Earth, Jupiter, and Saturn would hasten its return by rather more than 10 days, and he accordingly fixed the next perihelion passage for Nov. 27, 1832. Damoiseau's investigations yielded much the same result. In 1828 Olbers called attention to the fact that in 1832 the comet would pass within 20,000 miles of the Earth's orbit, but that as the Earth would not reach that particular point till one month after the comet had passed it, no danger was to be apprehended. Astronomers were quite satisfied as regards this matter, but their confidence was not shared by "the man in the street" (to use the hackneyed modern phrase) who was greatly alarmed lest a collision should take place, and our globe suffer damage or destruction.

[b] Certain French writers following Arago persist in calling this comet "Gambart's", but outside France Biela's name is universally attached to it. If the French writers in question object to Biela's name the very least they might be expected to do would be to call it "Montaigne's Comet". The association of Gambart's name with it is indefensible.

The comet returned to perihelion in Nov. 1832 within 12 *hours* of the time predicted by Santini. It was first seen at Rome on Aug. 23, but owing to its excessive faintness was not generally observed till two months later.

The next return was calculated to take place on July 13, 1839, but, in consequence of its close proximity to the Sun, the comet was not seen on that occasion.

Santini continued his researches and fixed on Feb. 11, 1846, for the next perihelion passage. This was anticipated by astronomers with great eagerness, because it was foreseen that the comet would be visible for a considerable period, and so there would be the chance of obtaining a good body of observations for correcting the theory of its motion. Di Vico at Rome discovered it on Nov. 28, 1845, and Galle at Berlin found it two days later; but it was not generally seen till the 2nd or 3rd week in December. The striking incident of the comet breaking up into two portions, alluded to in a previous chapter,[c] deserves further description.

The duplicity of Biela's Comet appears to have been first seen on Jan. 13, 1846, at Washington, U.S. Three weeks previously to this, however, Hind remarked a kind of protuberance towards the North of the nucleus which perhaps may be regarded as the first sign that something unusual was going to be developed. Two days after the American observation, that is to say on Jan. 15, Challis at Cambridge noticed for the first time the complete severance of the little comet from the big one. His description of what he saw, and his comments on the occurrence, are so very interesting as to deserve transcription. He published his notes in a letter to the President of the Royal Astronomical Society.

"On the evening of Jan. 15, when I first sat down to observe it, I said to my assistant, 'I see *two* comets.' However, on altering the focus of the eye-glass and letting in a little illumination, the smaller of the two comets appeared to resolve itself into a minute star, with some haze about it. I observed the comet that evening but a short time, being in a hurry to proceed to observations of the new planet. On first catching sight of it this evening (Jan. 23) I again saw two comets. Clouds immediately afterwards obscured the comet for half an hour. On resuming my observations I sus-

[c] See p. 15 (*ante*).

pected at first sight that *both* comets had moved. This suspicion was afterwards confirmed: the two comets have moved in equal degree, retaining their relative positions. I compared both with Piazzi, 0^h 120, and the motion of each in 50^m was about 7^s in R.A. and 10″ in N.P.D. What can be the meaning of this? Are they two independent comets? or is it a binary comet? or does my glass tell a false story? I incline to the opinion that this is a binary or double comet, on account of my suspicion on Jan. 15. But I never heard of such a thing. Kepler supposed that a certain comet separated in two, and for this Pingré said of him, 'aliquando bonus dormitat Homerus.' I am anxious to know whether other observers have seen the same thing. In the meanwhile I thought, with the evidence I have, I had better not delay giving you this information."

In a subsequent letter Professor Challis says:—

"There are certainly two comets. The north preceding is less bright and of less apparent diameter than the other, and, as seen in the Northumberland telescope, has a minute stellar nucleus. . . .

"The greater apparent distance between the comets on Jan. 24 is partly accounted for by their approaching the Earth. I saw the comets on Jan. 25, but took no observation. The relative positions were apparently unchanged.

"I think it can scarcely be doubted, from the above observations, that the two comets are not only apparently but really near each other, and that they are physically connected. When I first saw the smaller, on Jan. 15, it was faint, and might easily have been overlooked. *Now* it is a very conspicuous object, and a telescope of moderate power will readily exhibit the most singular celestial phenomenon that has occurred for many years—a double comet." [d]

The comets continued to be observed all through February and March. On March 24 one only was visible, and on April 22 both had disappeared. To O. Struve on Feb. 21 there appeared no material connection between the 2 bodies; but some days later Maury at Washington saw an arc of light extending from the large comet to the small one, forming a sort of bridge between the two. This was when the small comet was at its brightest. When the large comet had regained its superiority it threw out new rays, which gave it the appearance of having 3 tails, each adjacent tail making an angle of 120° with its neighbour, one of the tails being the bridge to the small comet.

Maury's words were:—

"No. 2 appears to have thrown a light arch of cometary matter from its head over to the other: and their tails stretching off below in the field, and nearly in a parallel direction, gives these 2 objects the singular and beautiful

[d] *Month. Not. R.A.S.*, vol. vii, p. 73. March 1846.

appearance of an arched way in the heavens, through which the stars are sometimes seen to pass."[e]

The total disappearance of Biela's Comet has now to be narrated. It returned again to perihelion in Sept. 1852, and was visible for 3 weeks in the condition of one principal comet with a baby comet of the same shape travelling alongside of it. The same reason which prevented it from being seen in 1839 also caused it to pass undetected in May 1859, so that its next anticipated return in Jan. 1866 was looked forward to with much interest. Would it return? Would the companion comet be there? If so, alongside the principal comet? or left behind at a greater or less distance? That the two would have to be treated as two distinct bodies was sufficiently shown to be the judgment of astronomers by the fact that in the sweeping ephemeris issued by Hind for facilitating their rediscovery in 1859 two independent sets of elements and positions were given.

But all in vain: neither the big nor the little comet were seen, nor have they ever been seen since, except, perhaps, in a totally transformed condition, as to which more anon. It was calculated that in 1865–6 the comet would be very favourably placed in the Heavens, and very elaborate search was made for it, unsuccessfully, at numerous European observatories.[f] Astronomers, with one exception, gave up the matter in despair. The exception was Klinkerfues of Göttingen. He kept his attention on the subject, and as the result of his labours he sent on Nov. 30, 1872, to Pogson, at Madras, a telegram worded as follows:—"*Biela touched Earth on 27th: Search near Theta Centauri.*" The search was made and with the extraordinary result that *a* comet was found. Observations of it were obtained on Dec. 2 and 3,

[e] *Month. Not. R.A.S.*, vol. vii, p. 91. May 1846.

[f] Some mysterious observations of alleged comets formed a topic of conversation at certain meetings of the Royal Astronomical Society in the spring of 1866, but there is no sufficient proof that they related to Biela's Comet. Talmage, one of the observers who said he saw something "cometic-looking" on Nov. 4, 1865, was an observer of experience and undoubted good faith. Buckingham, whose observation was on Nov. 9, 1865, had not the same repute as Talmage. (*Month. Not. R.A.S.*, vol. xxvi, pp. 241, 271.)

1872, but bad weather and the advance of twilight prevented any further observations. Pogson described his comet as circular; 75″ in diameter and having a bright nucleus with a bright but distinct spreading tail 8′ in length. This description would not seem to fit in with the description given of Biela's Comet at previous apparitions, but not much stress should be laid upon that fact. However, on other grounds it was the opinion of Bruhns that the comet seen by Pogson could not possibly be Biela's, but an unknown comet, which by a remarkable coincidence was in or near the place where Biela's Comet ought to have been seen.

The question stood and still stands for consideration, "Why has Biela's Comet disappeared?" The answer to this question seems now to belong not to the subject of cometary, but to that of meteoric astronomy, and will be discussed in a separate chapter.[g]

Di Vico's Comet.

This also is a comet which has a mysterious history, as to which questions are constantly cropping up which cannot be answered.

On Aug. 22, 1844, Di Vico at Rome discovered a telescopic comet which, towards the end of the following month, became visible to the naked eye. With a telescope a bright stellar nucleus and a short tail were seen. It soon became apparent that the comet was travelling in an elliptic orbit, to which Brünnow assigned a period of 1993 days. He calculated that the comet's next return to perihelion would occur in the spring of 1850, but that owing to the position of the comet in its orbit relatively to the Sun for some months, it would be impossible to see it at a sufficient distance clear of the Sun's rays.

The next return to perihelion was fixed for Aug. 6, 1855, and as theory suggested that the comet would be favourably situated for observation, hopes were entertained that it would be detected. They were, however, doomed to disappointment; and as a matter of fact, the comet has never for a certainty

[g] See p. 192 (*post*).

been seen since. Bearing in mind its size and brilliancy (unusual for a short-period comet), its non-appearance since 1844 is a remarkable fact, and one as to which no assured explanation can be given. Some computations by Le Verrier seemed to render probable that Di Vico's Comet was identical with the comet of 1678, and several other identifications have been suggested, but there is no certainty about any of them. It is, however, worth mentioning that the elements of Finlay's Comet (1886, vii.) closely resemble those assigned to Di Vico's Comet by Brünnow; but the resemblance appears to be fortuitous: that is to say that they are two distinct comets moving in orbits similar in many respects but not in all.[h]

On Nov. 20, 1894, E. Swift in California discovered a small comet, the elements of whose orbit closely resemble the elements assigned to Di Vico's Comet; and Schulhof and others are strongly impressed with the idea that the 2 objects are identical. Future years may help to clear up the matter. Should the question be decisively settled in the affirmative, we must assume that the comet is subject to marked changes of brilliancy. This comet was not seen either in the autumn of 1900, nor in July, 1907, when it was expected; and it must be regarded as "lost", unless it should be found in Dec. 1912. Its period has been put at 6·4 years.

This chapter may be suitably brought to a close by recording, without entering into much detail, certain comets to which short periods have been assigned, but as to which our knowledge remains too imperfect for much to be said.[i] These comets are the following:—

Grischau's (1743, i.)	Peters's (1846, vi.)
Helfenzrieda's (1766, ii.)	Tuttle's (1858, iii.)
Pigott's (1783, i.)	Coggia's (1873, vii.)
Blainpain's (1819, iv.)	

[h] Another instance of comets certainly different, but moving in orbits which are similar, has been already mentioned. See p. 84 (*ante*).

[i] The reader will find a few brief particulars in Hind's *Comets*, or Cooper's *Cometic Orbits*—two works which everybody interested in this branch of astronomy ought to possess. Those who read German will find Galle's *Verzeichniss der Cometenbahnen*, published in 1894, a useful book.

Grischau's Comet of 1743 (i.), discovered on Feb. 10, 1743, was very imperfectly observed for only a fortnight. Clausen assigned to it an elliptic orbit with a period of 5·43 years, and thought that the comet of 1819 (iv.) might be a return of it.

Helfenzrieda's Comet of 1766 (ii.) was discovered at Dillengen on April 1, and remained visible for 6 weeks. It had a tail 3° or 4° long. Burckhardt calculated for it an elliptic orbit, with a period of 5·0 years, but it has never been seen since. This is the more remarkable having regard to its size, and that the duration of its visibility was long enough one might suppose for the orbit obtained to be open to no doubt.

Pigott's Comet of 1783 (i.), was discovered at York on Nov. 19. Its orbit was undoubtedly elliptic, and Burckhardt assigned to it a period of 5·6 years: other computers obtained a longer period.

Blainpain's Comet of 1819 (iv.) was discovered at Marseilles on Nov. 28, 1819, and was observed at Milan until Jan. 25, 1820, a length of time fully sufficient to have yielded an accurate orbit. Encke investigated it and found it decidedly elliptical with a period of 4·8 years; but, strange to say, there have been no modern tidings of the comet.

Peters's Comet of 1846 (v.) was discovered at Naples on June 26, and observed there till July 21. Peters and D'Arrest agree in ascribing to it an elliptic orbit of short period. Peters's result was 12·8 years with an uncertainty of about 1 year. It was badly placed for observation in 1859 and 1872: nor was it seen in 1885 or 1898.

Tuttle's Comet of 1858 (iii.) was discovered at Cambridge, U.S., on May 2. A parabola was supposed at first to satisfy the observations, but subsequently elliptic elements were obtained, and periods of 5·8 years and 7·5 years were assigned by Schulhof; but nothing further is known of the comet.

Coggia's Comet of 1873 (vii.) was the subject of an elaborate investigation by Weiss, who thought it might be a return of the comet of 1818 (i.), discovered by Pons on Feb. 23, 1818; but he could not satisfy himself whether its period was 55·8, 18·6, or 6·2 years, though he gave the preference to 6·2 years.

CHAPTER VIII.

PERIODIC COMETS OF LONG PERIODS.

Periodic Comets of between 70 *and* 80 *years.—Westphal's* (1852, iv.).—*Pons's* (1812).—*Di Vico's* (1846, iv.).—*Olbers's* (1815).—*Brorsen's* (1847, v.).—*Halley's.—Particulars of each of these Comets.—Return of Pons's Comet in* 1883.—*Observations of it by Trépied and others.—Many comets no doubt revolving in elliptic orbits, but with periods of hundreds or thousands of years.—Selected List of some of these.—The Comets of* 1264 *and* 1556.—*The Comets of* 1532 *and* 1661.

Besides the periodic comets mentioned in the last chapter there are a large number of comets to which periods of far greater length have been assigned, amounting in many cases to thousands of years. It is obviously futile to talk about these as recognised members of the solar system, but there is a small group of 6 comets which may fairly be regarded as members of our system, although it must be confessed that at present only 3 out of the 6 have vindicated their claim by having appeared a second time. These comets are the following:—

No.	Name.	Period.	Probable next Return.
		Years.	
1	Westphal's (1852, iv.)	67·77	1913
2	Pons's (1812)	70·68	1955
3	Di Vico's (1846, iv.)	73·25	1919
4	Olbers's (1815)	74·05	1960
5	Brorsen's (1847, v.)	74·97	1922
6	Halley's	76·78	1910

It has been suggested that 4 of the above may have originally constituted a single comet; but independently of

this idea Kirkwood gave reasons why some connection may exist between Nos. 2 and 3 in the above table.

No. 1 was discovered by Westphal at Göttingen on June 27, 1852; and subsequently and independently by Peters at Constantinople. It was described as "pretty bright", and "above 1′ in extent"—language which does not err by being too definite.

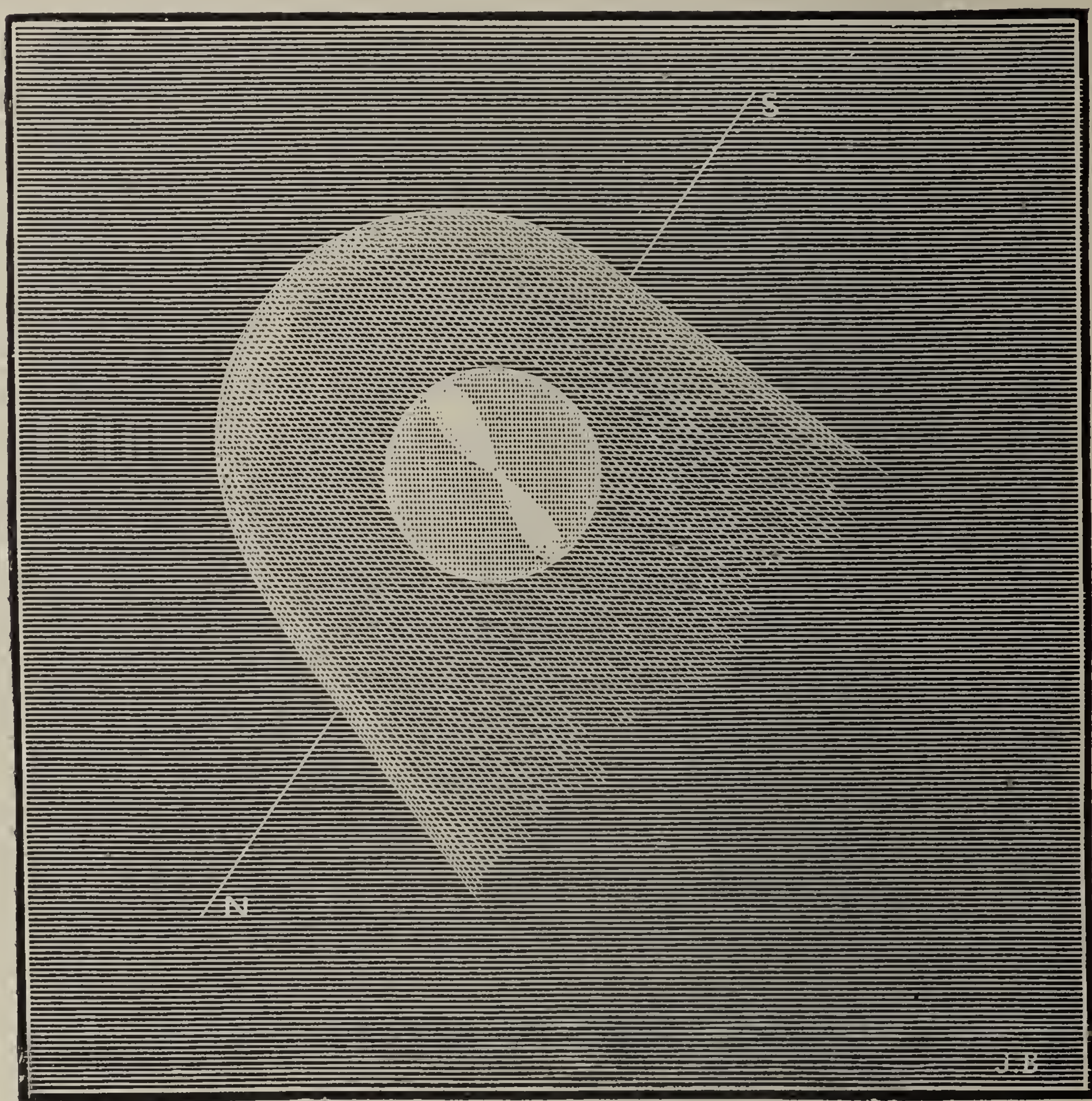
No. 2 was discovered by the indefatigable Pons on July 20, 1812, being the 16th comet found by him in 10 years. It had an irregular nebulous form without tail or beard, and was only visible with the aid of a telescope. Encke having assigned to it a period of about $70\frac{3}{4}$ years the return of the comet was anticipated about 1883, and accordingly a sweeping ephemeris for it was computed by Schulhof and Bossert. By the aid of this, Brooks in America found it on Sept. 3. It seems to have exhibited at this visit physical characteristics differing altogether from anything recorded in 1812, unless we assume that the observers of that date failed to do justice to the comet's features. Chandler in America and Schiaparelli in Italy saw it on several occasions in Sept. 1883, first as a nebulosity, then as a star, and then as a nebulosity again; whilst Müller at Potsdam on Jan. 1, 1884, observed changes backwards and forwards in magnitude and brightness to the extent of $\frac{7}{10}$ths of a magnitude, in $1\frac{3}{4}$ hours. Trépied observed it daily from Jan. 13 to 18 without noticing anything very remarkable; but on Jan. 19 the aspect of the nucleus had so changed that it was difficult to realise that the same object was being scrutinised as had been viewed on previous days. The head then exhibited 3 distinct zones as in Fig. 39.

"The interior and most brilliant zone was almost circular, and remarkable owing to its milky aspect: it stood out sharply from the adjoining zone and was of a leaden hue: outside this second zone came the ordinary nebulosity of the tail, having on the south-west side a parabolic outline.

"The nucleus had undergone a considerable lengthening; it consisted of 2 distinct parts of very different brilliancy united by a very well marked twisted link (*étranglement*) which occupied almost the centre of the inner circular zone. The Southern part of the nucleus, which was by far the brightest, was terminated by an elliptic arc very sharply defined and tangential to the circumference of the zone; the Northern part on the contrary was suddenly cut off at the extremity of the diameter, whose

direction coincided with that of the axis of the nucleus. This direction was almost exactly identical with that of the axis of the tail. On January 20 the nucleus and the nebulosity which surrounded it had resumed their accustomed aspect. I observed the comet up till the end of the 1st week in February without being able to detect any changes like that which happened on Jan. 19. It follows therefore that the transformations in question must have run their course in a few hours; and herein consists the remarkable character of the whole phenomenon."

Fig. 39.



PONS'S COMET: JAN. 19, 1884. (*Trépied.*)

Trépied's observations accord generally with those of Perrotin, Thollon, and Rayet, which apply, however, to the date of Jan. 13. It would appear from these various observations, taken together, that this comet underwent changes which, whatever their nature, were in some sense periodic—a circumstance additionally remarkable.

No. 3.—Di Vico's Comet of 1846 (iv.) was discovered on Feb. 28, and though his name is commonly attached to it, it seems to have been found by Bond at Cambridge, U.S., two days previously. It was under observation for more than two months, and there does not appear to be any reason for doubting that its period is much about what is stated in the Table, or between 72 and 73 years.

No. 4.—Olbers's Comet of 1815 was discovered by him at Bremen on March 6, and was last observed on Aug. 26. Bessel made the periodic time in 1815 to be 74·04 years, whilst Nicolai made it 74·79 years. Bessel calculated the perturbations onward to the next perihelion, and found that the comet's return would be so expedited that the perihelion passage would take place about February 9, 1887. This forecast was not, however, borne out by the result, for the comet did not pass its perihelion till Oct. 8. The comet was discovered by Brooks in America on Aug. 24 and remained visible for 2 months.

No. 5.—Brorsen's long-period Comet was found on July 20, 1847, at Altona, and was observed for 8 weeks. Its orbit was investigated by several astronomers, and there seems no reason to doubt the accuracy of the period assigned by D'Arrest, namely, nearly 75 years.

The 6th and last comet enumerated in the Table prefixed to this chapter, namely, "Halley's", is one of such extreme interest, and has such a long history, extending back as it does for nearly or quite 2000 years, that it must have a chapter to itself; and this chapter will be completed by a brief enumeration of some of the comets whose periods have, with some reasonable probability, been estimated at hundreds or thousands of years. But after all said and done, however near the truth these figures may, or may not, be, it is obvious that they have little practical interest for us except as showing the possibilities of calculation as applied to comets. However, for what they are worth here are some of them :—

Comet's Date.	Period in Years.
The Comet of 1864 (ii.)	2,800,000
The Comet of 1863 (i.)	1,840,000
The Comet of 1882 (i.)	400,000
The Comet of 1845 (ii.)	115,000
The Comet of 1844 (ii.)	102,050
The Comet of 1898 (x.)	87,000
The Comet of 1780 (i.)	75,314
The Comet of 1847 (iv.)	43,954
The Comet of 1877 (iii.)	28,000
The Comet of 1680	15,864
The Comet of 1874 (iii.)	13,918
The Comet of 1840 (ii.)	13,864

It would be a waste of space to extend this Table, but of course there are many comets on record with periods less than 10,000 years and more than 80 years.

Amongst the long-period comets enrolled as such by astronomers the Comet of 1264 seems to deserve some special mention, and for a threefold reason: its magnificent brilliancy; the great amount of time which has been dedicated to the study of its orbit during a century and a half, beginning with Halley and ending with Hind; and the extreme disappointment experienced both by astronomers and the public at its non-appearance in 1858 or in the years immediately following, for it was assumed that another very grand comet which appeared in 1556 was identical with it.

Making every allowance for the extravagance of the language often employed in bygone centuries to describe comets, it seems extremely probable that both these comets must have been comets of remarkable brilliancy. The observations of both have been handed down with unusual perspicuity both by Chinese and European writers; and the numerous and experienced computers who have worked at their orbits had no difficulty in arriving at the conclusion that the comets were identical, and that the period was something between 302 and 308 years. Reckoning backwards, Hind also found

that, allowing for planetary perturbations, a great comet which appeared in 975 followed a path which might be very closely represented by a comet with the elements of the comet of 1556. Hind even went one step further, and concluded that "a comet observed in China in the summer of 683, and one seen in the circumpolar heavens A. D. 104, present some indications of identity with the grand comet of 1264 and 1556, but the accounts we possess are too vague to admit of anything more than conjecture".[a]

It can well be imagined that this comet left its mark on history. In 1264 it was considered to have announced the death of Pope Urban IV; whilst, having regard to the particular time when it appeared in 1556, it was considered to have brought about the abdication of the Emperor Charles V. This, however, must be regarded as an exploded romance, because the Emperor abdicated in 1555, but a thrilling story was long in circulation based on materials gathered (I will not say invented) by the great French cometographer Pingré.

There are some comets moving in elliptic orbits which cannot conveniently be grouped, but which should be mentioned. One of these is the Comet of 1661, which has been supposed to be identical with the Comet of 1532. Halley and Méchain both computed the orbit of the latter comet, as did Méchain that of the Comet of 1661. The orbits obtained for the Comet of 1532 differed materially, and Olbers, who made an independent calculation, upheld Halley's results, and assigned to the comet a period of 129 years. If this conclusion was well founded the comet should have returned about 1789 or 1790, but it is not known to have done so. However, to this negative evidence too much importance must not be attached. It remains to be seen whether the comet reappears in or about the year 1918. Sir J. Herschel picked out a number of other comets as supplying coincidences of interval backwards, but it does not appear that he carried out any rigorous investigations respecting them.

[a] *The Comets*, p. 123.

CHAPTER IX.

HALLEY'S COMET.

Halley's Comet by far the most interesting of the Periodic Comets.—Sir I. Newton and the Comet of 1680.—*This Comet the first to which the theory of Gravitation was applied.—The Comet of* 1682.—*Description of it by various observers.—Luminous Sector seen by Hevelius.—Halley's application to it, and the Comets of* 1531 *and* 1607, *of Newton's mathematical researches.—He finds the elements of the three very similar, and suspects the three comets are really one.—With a probable period of* 75 *years.—Suspects the disturbing influence of planets on Comets.—Of Jupiter's influence especially.—Halley's final conclusion that the Comet would reappear in* 1758.—*Preparations by Clairaut and Lalande to receive it.—The Comet found by an amateur named Palitzsch near Dresden.—Some account of this man.—The Comet generally observed in Europe.—Trick played by Delisle on Messier.—Return of the Comet in* 1835.—*Great preparations by Mathematicians to receive it.—These specially took into account planetary perturbations.—Predicted date of perihelion passage.—The Comet discovered by telescopes as expected.—Some particulars of the observations.—The past history of Halley's Comet traced back through many centuries.—Researches of Hind.—Confirmed in the main by Crommelin and Cowell.—Some quotations from old Chroniclers.—Observations by the Chinese of great value.—Halley's Comet in* 1066.—*Figured in the Bayeux Tapestry.—The Comet's various returns ascertained with certainty backwards to* B. C. 250.

The comet known as Halley's may be regarded as by far the most interesting of all the comets recorded in history; and this, whether looked at from the standpoint of the historian or of the astronomer; and having regard to the position which it has occupied during many centuries in the public mind, and is likely also to occupy during the year 1910, it will be worth while to review its career in some detail.

A few years after the advent of the celebrated Comet of 1680 Sir I. Newton published his epoch-making *Principia*, in which he first promulgated the Theory of Gravitation, and applied it to the orbit of that comet. He explained the

EDMUND HALLEY.

method of determining by geometrical construction the visible portion of the path of the comet, and invited astronomers to apply these principles to the comets on record, or some of them. He considered that it was very probable that some comets might move in elongated ellipses which near perihelion would scarcely be distinguishable from parabolas; and he even thought that the recent Comet of 1680[a] might be moving in an ellipse the circuit of which would occupy about 575 years.

Fig. 40.

MEDAL STRUCK IN GERMANY TO ALLAY THE TERROR CAUSED BY THE COMET OF 1680.

"The star threatens evil things: Only Trust!
God will make things turn to good."

Halley (to whose exertions the publication of the *Principia* was in great measure due, for he bore the labour and expense of its publication) also took this view. Although we now know that the period of that comet is measured by thousands of years Halley's investigations were not without good fruit, for they may be said to have drawn him into a systematic

[a] It should perhaps be mentioned, if only in the humble form of a foot-note, that this Comet of 1680 gave rise to a special sensation some years after its appearance. A clergyman named Whiston, best known to fame as the editor of a standard edition of the works of the Jewish historian Josephus, published in 1696 *A New Theory of the Earth*, in which he sought to explain by the supposed agency of a comet the geological records of the Book of Genesis. At first he based his theory upon nothing except his own imagination, but when he found that Halley had (erroneously) ascribed to the Comet of 1680 a periodic time of 575 years, Whiston, working backwards the materials of history and fable within his reach, ascribed the Noachian Deluge to one of the regular visits of this comet, and added that it would be by a future visit of the same comet that the prophecies of Holy Scripture as to the destruction of the World would be made good. I think this is sufficient to indicate the value of the Rev. William Whiston's labours in the field of comets.

study of cometary orbits which ended, as we shall soon see, in a famous and remarkable prediction. He undertook to investigate the movements of a large number of the comets previously recorded, with the view of ascertaining whether any, and if so which, of them had appeared to follow the same path. Careful investigation soon showed that the orbits of the Comets of 1531 and 1607 were similar to each other, and similar in fact to that of the Comet of 1682 seen by himself.

On Aug. 15, 1682, Flamsteed's assistant at the Royal Observatory, Greenwich, discovered a comet. A few days later the diameter of the head was about 2′ of arc, and it had a tail 5° long. On Aug. 21 the tail had become 10° long. Flamsteed's observations seem not to have extended beyond Sept. 9, when the head had become enfeebled and was scarcely visible in the twilight. Halley himself, however, saw it a day later. Picard at Paris found the comet on Aug. 26, the head shining as a star of mag. 2. On Aug. 29 the tail was curved, the concavity being on the E. side. On Sept. 11 the head was so confused that it was only with difficulty that a luminous point could be perceived. Picard's last observation was on Sept. 12. Hevelius at Dantzig says that the comet was bright at the end of Aug. and could be seen all night with a tail from 12° to 16° long. In large telescopes a nucleus of an oval or gibbous form was constantly noticed. It was also remarked that on many occasions the direction of the tail was not exactly *from* the Sun, as P. Apian's observations of earlier comets suggested.[b] The most remarkable of the matters mentioned by Hevelius was the existence of a luminous ray, or sector, thrown out from the nucleus into the tail. He has left behind a picture of this which is reproduced in the opposite woodcut (Fig. 41).

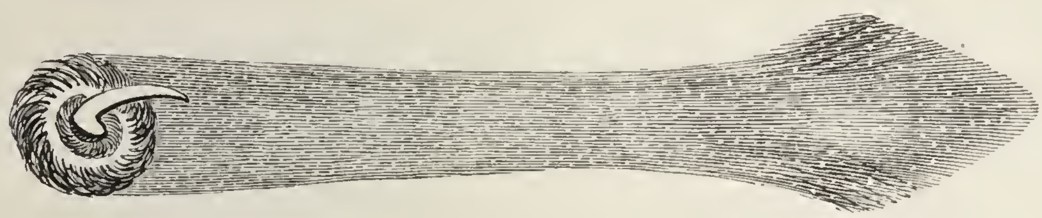
This ray was first noted about Sept. 8, and even making every allowance for the vagaries of the astronomical artists of the 17th century it is impossible to doubt that some sort of ray of light was thrown out from the head of the comet, and we shall presently see that the same thing happened in 1835.

[b] See p. 22 (*ante*).

The Comet of 1682 seems to have been very generally observed by all the principal astronomers of the time, and amongst those who have left behind them observations we find the familiar names of Kirch of Leipzig, and Montanari of Padua; and the less familiar names of Zimmermann of Nuremberg and Baërt of Toulon.

Halley, making use of Flamsteed's observations, calculated parabolic elements of the comet in accordance with the rules laid down by Newton; and having also determined by the same methods the orbits of the Comets of 1531 and 1607 he was immediately struck by their similarity, and suspected from "the like situation of their planes and perihelions that the comets which appeared in the years 1531, 1607, and 1682

Fig. 41.



HALLEY'S COMET, JAN. 9, 1683 (N. S.), SHEWING LUMINOUS SECTOR.
(*Drawn by Hevelius.*[c])

were one and the same comet that had made three revolutions in its elliptical orbit". This supposition implied that the comet's period was somewhere about $75\frac{1}{2}$ years. There were nevertheless 2 circumstances which might be supposed to offer some difficulty, inasmuch as it appeared that the intervals between the successive returns were not precisely equal; and that the inclination of the orbit was not exactly the same in each case. Halley, however, "with a degree of sagacity which, considering the state of knowledge at the time, cannot fail to excite unqualified admiration, observed that it was natural to suppose that the same causes which disturbed the planetary motions would likewise act on comets"; in other words, that the attraction of the planets might be expected to

[c] *Annus climactericus*, p. 139.

exercise some disturbing influence on the motions of comets. The discrepancies already pointed out in the orbits of the 3 comets just mentioned made Halley hesitate for some time as to their identity, and in his memoir on comets published in 1705[d] he only, as it were, hinted his suspicions. Eventually, however, he became much more confident. This appears to have been the result of his investigations as to the probable influence of the Planet Jupiter. He found that between 1607 and 1682 the comet had passed so near Jupiter that its velocity in its orbit must have been considerably augmented, and its period, consequently, shortened; he was therefore induced to *predict* its return about the end of 1758 or the beginning of 1759. Finally, when he had matured his labours, he thus plaintively wrote on the subject:—"Wherefore if it should return according to our prediction about the year 1758 impartial posterity will not refuse to acknowledge that this was first discovered by an Englishman." On this Hind judiciously remarked as follows:—"Nor has posterity attempted to deprive him of the honours which were his due; his discovery forms an epoch, and an important one, in the history of Astronomy. His calculations must have been laborious in the extreme. He assures us himself they were 'prodigiously' long and troublesome; but the zeal which induced such an amount of exertion was well rewarded by the final result."[e]

Halley's first formal announcement of his expectations concerning his comet appears to have been in the paper presented to the Royal Society, in which the following passage (in Latin) occurs:—"Now many things lead me to believe that the Comet of the year 1531, observed by Apian, is the same as that which, in the year 1607, was described by Kepler and Longomontanus, and which I saw and observed

[d] *Phil. Trans.*, vol. xxiv, pp. 1882–99, 1704–5. The memoir is entitled *Astronomiæ Cometicæ Synopsis*. It was translated from Latin into English first of all in John Harris's *Lexicon Technicum*, vol. ii, London, 1710, and afterwards it was not *republished* but a new version was prepared, in D. Gregory's *Elements of Physical and Geometrical Astronomy*, 2 vols. London, 1726.

[e] Hind, *The Comets*, p. 38.

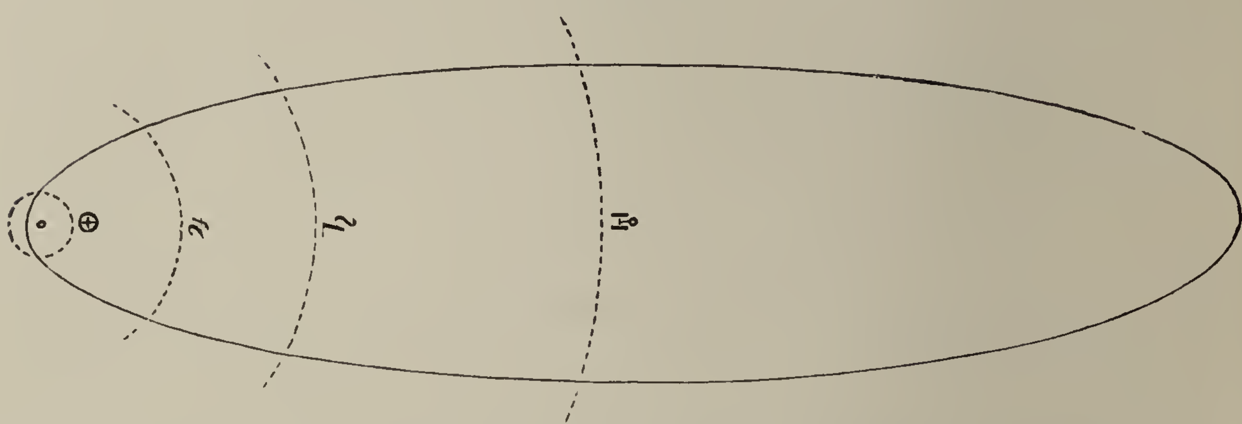
myself, at its return in 1682. All the elements agree, except that there is an inequality in the times of revolution; but this is not so great that it cannot be attributed to physical causes. For example, the motion of Saturn is so disturbed by the other planets, and especially by Jupiter, that his periodic time is uncertain, to the extent of several days. How much more liable to such perturbations is a comet which recedes to a distance nearly 4 times greater than Saturn, and a slight increase in whose velocity could change its orbit from an ellipse to a parabola? The identity of these comets is confirmed by the fact that in the summer of the year 1456 a comet was seen, which passed in a retrograde direction between the Earth and the Sun, in nearly the same manner; and although it was not observed astronomically, yet, from its period and path, I infer that it was the same comet as that of the years 1531, 1607, and 1682. I may, therefore, with confidence predict its return in the year 1758. If this prediction be fulfilled, there is no reason to doubt that the other comets will return."

Halley died in 1742 and was buried in the Churchyard of St. Margaret's, Lee, not far from Greenwich, and it has lately (1909) been announced that the Admiralty have decided to repair his tomb at the public expense, no descendants of his being known. The original top slab with an inscription was illegally removed to the Greenwich Observatory in 1854. Let us hope that it will be now restored, or a new one with the original inscription put in place.

As years rolled on and 1758 began to draw near astronomers naturally recalled Halley's prediction, and thought it worth while to rely upon it in making preparations to receive the comet. The French astronomer Clairaut was the man who took the matter most seriously in hand, the important question being to ascertain the extent of the perturbations of the comet's orbit likely to be brought about by the influence of Jupiter and Saturn. The history of the steps taken cannot be better described than in the words of Hind:—"Having devised a method which appeared to possess all needful accuracy, he commenced, in conjunction with the celebrated

Lalande and a lady, Madame Lepaute, the immense mass of calculations requisite for the complete attainment of his object. It was necessary to compute the distances of the comet from the disturbing planets, Jupiter and Saturn, not only from 1682, when it was last observed, but for the previous revolution, or for a space of more than 150 years. This of itself was a most laborious business; but the succeeding part of the work, where the disturbing force of each planet was required for this long period, involved much greater and more intricate calculations. Lalande minutely describes the plan adopted: for 6 months they computed from morning to night, with but little intermission, even, as he states, at meals; and he mentions, as one result of this assiduous attention to the

Fig. 42.



PLAN OF THE ORBIT OF HALLEY'S COMET COMPARED WITH THE ORBITS OF CERTAIN PLANETS.

work, that he contracted an illness which remained upon him during the rest of his life. Madame Lepaute's assistance is said to have been so important, that without it they would hardly have completed the investigation before the comet re-appeared. However, by dint of these extraordinary exertions, the calculations were brought to a close."

On Nov. 14, 1758, Clairaut announced in a paper addressed to the Academy of Sciences at Paris, that by the influence of Jupiter the comet would be retarded 518 days, and that to this must be added 100 days due to Saturn, so that the total retardation would be 618 days, or about 20 months. On this basis he predicted April 13, 1759, as the date of the coming

perihelion passage. He did this, however, with a slight reservation, because, having neglected some small quantities in the calculations, he thought that the date named might be wrong by a month either way. When Clairaut's conclusions became generally known the astronomers of Europe were soon on the *qui vive*, and several of them carried out a prolonged watch of the heavens, which in Messier's case extended over the whole of the year 1758. It was not destined, however, that a professional astronomer should be the first to detect the comet on its anticipated return; that honour was reserved for an amateur student of Nature, said to have been a farmer by occupation, named Palitzsch, living at Prohlis, near Dresden, who saw it on the night of Christmas Day, 1758, with a telescope of 8 ft. focus. Some curious misstatements respecting this man have been widely circulated, and perhaps even to this day may be considered as still in circulation. Baron De Zach, who was personally acquainted with the man, has left on record some interesting particulars relating to him. Farmer though he was, he was a diligent student of Astronomy; was possessed of a strong sight; and was in the habit of scrutinising the heavens with the naked eye, which fact may perhaps have given rise to the statement that he found Halley's Comet with the naked eye at a time when the professional astronomers were vainly searching for it with their telescopes. The first man of note to find the comet appears to have been Messier, who caught it in bad weather on Jan. 21, and observed it regularly for 3 weeks. It seems that Delisle, then Director of the Observatory of Paris, would not allow Messier (who was his assistant) to disclose the fact of his discovery, and he remained the only professed astronomer who saw the comet before it became lost in the Sun's rays at its perihelion passage. Let us hope that Hind's remark on this incident will remain true:—"Such a discreditable and selfish concealment of an interesting discovery is not likely to sully again the annals of Astronomy." This strange conduct of Delisle's carried its own punishment, for when Messier's observations were afterwards published some members of the French Academy treated them as

forgeries; but there appears to have been no sufficient ground for this imputation, and it was eventually withdrawn. It remains to be added that the comet passed its perihelion on March 12, 1759—just within the limits assigned by Clairaut. After that, it was seen throughout Europe during April and May, although to the best advantage only in the Southern Hemisphere. On May 5, it had a tail 47° long.

Previous to the return of the comet in 1835, numerous preparations were made to receive it.

The great progress which had been made since 1759 in telescopes and methods of observation, especially under the inspiration of the two Herschels, Sir William and Sir John; and also in mathematics applied to celestial motions by men like Laplace, Lalande, La Grange, and other eminent foreigners, rendered the study of the movements of this comet, both visually when the time came to see it, and mathematically, before that time, a problem of great interest. As long before the expected return of the comet as 1817 the Academy of Sciences at Turin offered a prize, open to astronomers of all nations, for an Essay on the perturbations undergone by the comet since 1759. Baron Damoiseau of Paris gained the prize, and his Essay was published in 1820 in the *Memoirs of the Turin Academy*, vol. xxiv. The following outline of the researches of Damoiseau and others is epitomised from Hind's statement of them.

After calculating the effects of the attraction of the larger planets he fixed Nov. 4, 1835, at 8 p.m., Paris M.T., as the moment of the comet's perihelion passage. After Damoiseau, another Frenchman, Count de Pontécoulant, took up the matter, more or less on the same lines as Damoiseau, with the result that his date for the perihelion was rather more than a week later than Damoiseau's, or to be exact, he fixed the perihelion for Nov. 12, at 17^{h}, Paris M.T. The investigations both of Damoiseau and Pontécoulant were in a sense defective because both of them had omitted to take account of certain of the planets whose influence counted for something. Accordingly a German computer, Rosenberger of Halle, started on a new and independent investigation.

Damoiseau and Pontécoulant had neither of them attached sufficient importance to the actual ellipse described by the comet in 1759. As 1759 was the starting-point from which to determine the probabilities of 1835, it was important to obtain the most accurate knowledge possible of the condition of things in 1759. Rosenberger thought that he ought to go much further back than either Damoiseau or Pontécoulant had done, and that it would be impossible to make a trustworthy prediction for 1835 unless he began as far back as 1682, and computed the perturbations between 1682 and 1759, and so led up to 1835.

In performing his task Rosenberger took account not only of the influence of the great planets Jupiter, Saturn, and Uranus, but also of the smaller influence exerted by Venus, the Earth, and Mars, with some allowance also for Encke's supposed Resisting Medium as affecting his (Encke's) Comet. Omitting in the first instance any allowance for a Resisting Medium Rosenberger named Nov. 11, at 0^h Paris M.T., for the comet's perihelion passage. If an allowance supposed to be appropriate were made for a Resisting Medium the perihelion would fall about a week earlier or on Nov. 3 at 19^h Paris M.T. The actual effects on the comet's motion ascribed to the smaller planets were as follows:—the Earth $15\frac{2}{3}$ days, Venus about $5\frac{1}{3}$ days, and Mercury and Mars together nearly 1 day. By these periods of time (namely, about 22 days) added together, Rosenberger considered that the comet's return would be hastened. "Professor Rosenberger's investigation is remarkable for its extraordinary completeness, for the pains taken to include every possible source of perturbation, without regard to the numerical labour, and for the masterly manner in which the whole of the vast work was conducted."

Rosenberger, however, had a competitor in his own country. Lehmann thought there was room for another discussion of the elements and disturbances of the orbit of Halley's Comet, and though his labours were not in some respects as meritorious as Rosenberger's they have a merit of their own, inasmuch that Lehmann took the year 1607 as his starting-point. On this basis he fixed Nov. 26 for the perihelion passage, which

was a date a fortnight later than Pontécoulant's and 3 weeks later than Damoiseau's.[f]

As early as Dec. 1834, astronomers began to direct their telescopes to that part of the heavens where it was supposed that the comet would be first seen. Olbers had thrown out suggestions that it might be possible to find the comet between Dec. 1834 and April 1835, notwithstanding that the perihelion passage would not take place till many months later. Olbers's suggestion was largely acted upon, for it applied to the constellations Auriga and Taurus which were very favourably placed for observation in Northern and Central Europe, while Sir John Herschel at the Cape employed his great reflector also in sweeping for the anxiously expected body. But all these early efforts were wasted.

It was not until the morning of Aug. 6 that the first view of the comet was obtained, and the fortunate man was Dumouchel, director of the Collegio Romano Observatory at Rome, using a powerful telescope in a splendid climate. The comet was close to the computed place which was near ζ Tauri. It was a faint, misty object, discernible with difficulty, and moonlight and unfavourable weather during the next following days delayed the comet's discovery elsewhere. However, on Aug. 21 W. Struve found it with the great telescope at Dorpat, and during the following week it was seen at all the principal English and Continental observatories. The Dorpat observations showed that Rosenberger's predicted place was only 7′ of arc wrong in R. A. and 17′ in Declination. The effect of this error was to retard the perihelion passage till Nov. 16, or 5 days later than the epoch fixed upon by Rosenberger. During the first 3 weeks of Sept. the comet's brightness gradually increased, and on the 23rd it was seen with the naked eye by Struve, and on the following day with the naked eye by Kaiser at Leyden, though it was not

[f] The distracting effect of planetary perturbations on the movements of comets is shown by the fact that whereas the interval between the perihelion passages of Halley's Comet in 1835 and 1910 is to be set down at 74 years $5\frac{1}{2}$ months (the shortest on record), in 1222 and 1301 it was 79 years 2 months (the longest on record, the next longest having been 1066 and 1145).

sufficiently bright to attract general notice till the end of the month. A tail was first seen on Sept. 24, and during October the comet was more or less conspicuous, but observers differed very much in their estimates of the maximum length of the tail. The average of the estimates would seem to have been from 20° to 25°, though one observer did put it at 30°. The comet was lost to view about the time of perihelion passage disappearing below the S. W. horizon, and having, according to most accounts, lost its tail before the comet itself was lost to view. After the perihelion passage the comet was again observed at some of the southern observatories of Europe and at the Cape of Good Hope from Dec. 30 to the middle of May 1836.

Smyth's observations deserve to be quoted. Under the dates of Oct. 10 and 11 he wrote:—

"Oct. 10. The Comet in this evening's examination presented an extraordinary phenomenon. The brush, fan, or gleam of light, before mentioned, was clearly perceptible issuing from the nucleus, which was now about 17″ in diameter and shooting into the coma; the glances at times being very strong, and of a different aspect from the other parts of the luminosity. On viewing this appearance it was impossible not to recall the strange drawing of the 'luminous sector' which is given by Hevelius in his *Annus Climactericus* as the representation of Halley's Comet in 1682 and which had been considered as a distortion. [See Fig. 41, *ante.*]

"Oct. 11. . . . The tail was increasing in length and brightness, and, what was most remarkable, in the opposite direction to it there proceeded from the coma across the nucleus a luminous band or lucid sector more than 60″ or 70″ in length and about 25″ broad, with 2 obtuse-angled rays, the nucleus being its central point. The light of this singular object was more brilliant than the other parts of the nebulosity, and considerably more so than the tail; it was therefore amazingly distinct. On applying as much magnifying power as it would bear, the nucleus appeared to be rather gibbous than perfectly round: but with the strange sector impinging it was a question of difficulty."

The observations made at the Cape of Good Hope by Maclear disclose a succession of phenomena somewhat calculated to chill the enthusiasm of any who may be expecting great things of Halley's Comet in 1910. However, that is no reason for suppressing the observations. Though the perihelion passage took place on Nov. 15, 1835, Maclear did not begin to see the comet, or at any rate to record what he saw,

till Jan. 24, 1836. He says that the alteration of form which had taken place between the beginning of November and this date, during which interval the comet had been lost in the Sun's rays, was " remarkable ", and he goes on as follows :—

"Jan. 24. To the naked eye it was as bright as a star of the 2·3 or 3rd magnitude : there was no tail. In the 14-feet reflector, it presented an opaque, circular, planetary disc, tolerably well defined, encompassed by a delicately bright coma or halo, which was likewise circular.

"Crossing the disc in a direction not deviating much from parallelism with the equator, appeared an oblong, elliptical body, distinguished from the rest of the disc by its superior whiteness, and a semblance of greater density. The diameter of the disc measured 2′ 11″; of the coma, 8′ 12″.

"On the 25th, the circularity of the preceding limb of the cometary disc was partially broken, its dimensions were increased, the elongated portion was better marked, and its following end was brighter than the preceding.

"On the 26th, the halo had diminished, and the dimensions of the disc, or body, as it should now be called, were further increased. A spot like a nucleus could be occasionally seen in the brighter end of the oblong portion.

"On the 28th, the halo or coma had vanished. The nucleus was distinct, like a faint small star in the following end of the oblong portion. The dimensions of the body had greatly increased, while the intensity of its light had proportionately diminished. The general outline of the cometary body seemed approximating to a parabolic curve, the preceding end of which might be represented by conceiving the tail, as seen before the perihelion passage, abruptly separated from the head, leaving a serrated or ragged outline. The oblong portion with the nucleus resembled a small comet inclosed in the body of a larger one.

"On the 30th, the body was rather more elongated. A line drawn transversely through the nucleus measured 11′ 42″, being 5 times the diameter on the 24th ; or 29 times the area of a circle of which 2′ 11″ is the diameter. But the visible area of the whole body on the 30th could not be less than 35 times that of the 24th, excluding the halo. The nucleus was nearer to the S. than to the N. side by 32″.

"Throughout the succeeding three months the coma went on increasing, until the outline finally became so faint as to be lost in the surrounding darkness, leaving a blind, nebulous blotch with a bright centre enveloping the nucleus of variable brightness, depending on moonlight or the state of the atmosphere, and variable distance."[g]

The physical appearance of Halley's Comet at the 1835 apparition seems to have been in many respects very remarkable, and, did the statements made not emanate from some of the most distinguished astronomers of the time, it might be permissible to distrust them. It is impossible, however, to

[g] *Mem. R.A.S.*, vol. x, p. 92. 1837.

distrust anything stated by such men of skill and high character as Bessel, J. Herschel, W. Struve, and Maclear. Struve compared the appearance of the nucleus about the end of the first week of October to a fan-shaped flame emanating from a bright point; and subsequently to a red-hot coal of oblong form. On Oct. 12 it appeared like the stream of fire which issues from the mouth of a cannon at a discharge and when the sparks are driven backwards by

Fig. 43.

HALLEY'S COMET, 1835, OCT. 11. (*Smyth.*)

a strong wind. At moments the flame was thought to be in motion, or exhibiting scintillations similar to those of an Aurora Borealis. A second small flame forming a great angle with the principal one was also remarked. On Nov. 5 the nebulosity independently of the flames (two of them being visible) had a remarkable arched form somewhat resembling a "powder horn". These phenomena, under different and varying names, were seen and commented upon by other astronomers, British and foreign. The annexed sketch by

Admiral Smyth would seem to represent fairly well all the remarks made by the various astronomers just cited.

I have given these details respecting Halley's Comet in 1835 at some length, thinking that they might be useful as hints to observers as to what to look for in 1910.[h]

Before proceeding to deal with the preparations which have been made against the return of Halley's Comet in 1910, it will be interesting to consider what we know of the history of this comet anterior to the apparitions already mentioned. Halley, we have seen, satisfactorily traced back his comet to 1531, but since his time it has been traced very much farther backwards, through a range indeed of some 14 centuries or more, first by the labours of Hind,[i] and Laugier,[k] and quite recently by those of Cowell and Crommelin[l] confirming Hind for the most part, and enlarging his results. The years in which identification may be regarded as more or less certain are the following[m]:—

Year.	Interval in Years.	Year.	Interval in Years.
B. C. 11·8	77·8	989·7	76·5
A. D. 66·0	75·1	1066·2	79·0
141·2	77·2	1145·3	77·6
218·2	77·0	1222·9	79·3
295·2	78·6	1301·8	77·0
373·8	77·6	1378·8	77·6
451·5	79·3	1456·4	75·2
530·8	76·5	1531·6	76·1
607·3	77·5	1607·8	74·9
684·8	75·6	1682·7	76·5
760·4	76·8	1759·2	76·7
837·2	75·0	1835·8	74·5 ?
912·2	77·4	1910·3 ?	

[h] Drawings by Bessel will be found in the *Ast. Nach.*, vol. xiii, Nos. 300–2. Feb. 10, 1836. Reference may also be made to the *Memoirs of the Astronomical Society*, vol. x (drawings by C. P. Smyth); Sir J. Herschel's *Results of Astronomical Observations at the Cape of Good Hope*; and Struve's *Beobachtungen des Halleyschen Kometen.*

[i] *The Comets*, p. 50 *et seq.*

[k] *Comptes Rendus*, vol. xxiii, p. 183. 1846.

[l] *Month. Not. R.A.S.*, vol. lxviii. 1908. (Five separate papers, at pp. 111, 173, 375, 510, 665.)

[m] This table is from Hind, but

Cowell and Crommelin have found themselves justified in adding to this table, backwards, the years B.C. 87 (May) and 240 (May); with no identification possible for the intermediate return in June, 163 B.C., though comets are vaguely mentioned in the years 166 and 165.

We owe the observations which have made these identifications possible mainly to Chinese records, supplemented, more or less, by European monastic chroniclers of various sorts and kinds, and by a few private authors. It would be tedious to transcribe any of the originals of these, even in an abridged form; indeed, in point of fact their language is already generally so curt as to be incapable of abridgement, so a concise digest is all that will be offered to the reader and this will be often given in the language of Hind [n] and chronologically backwards.

Halley surmised that the great Comet of 1456 was identical with his, and Pingré converted Halley's suspicion into a certainty. This comet was described by the Chinese as having had a tail 60° long, and a head which at one time was round, and the size of a bull's eye, the tail being like a peacock's!

At the preceding return in 1378 the comet was observed both in Europe and China; but it does not appear to have been as bright as in 1456.

In 1301 a great comet is mentioned by nearly all the historians of the period. It was seen as far North as Iceland. It exhibited a bright and extensive tail which stretched across a considerable part of the heavens. Hind rejected the European observations of 1301, finding them to be of no good compared with the Chinese observations which proved consistent—a reversal of 20th-century preferences!

The previous apparition was for some time a matter of doubt. Hind treated as Halley's a comet which appeared in July 1223, and was regarded as the precursor of the death of

altered where necessary to embrace the researches of Cowell and Crommelin. It should here be mentioned that some share of credit for these identifications is due to the French astronomer Laugier. (*Comptes Rendus*, vol. xxiii, p. 183. 1846.) Nor should the labours of Pingré and Burckhardt be forgotten in this connection.

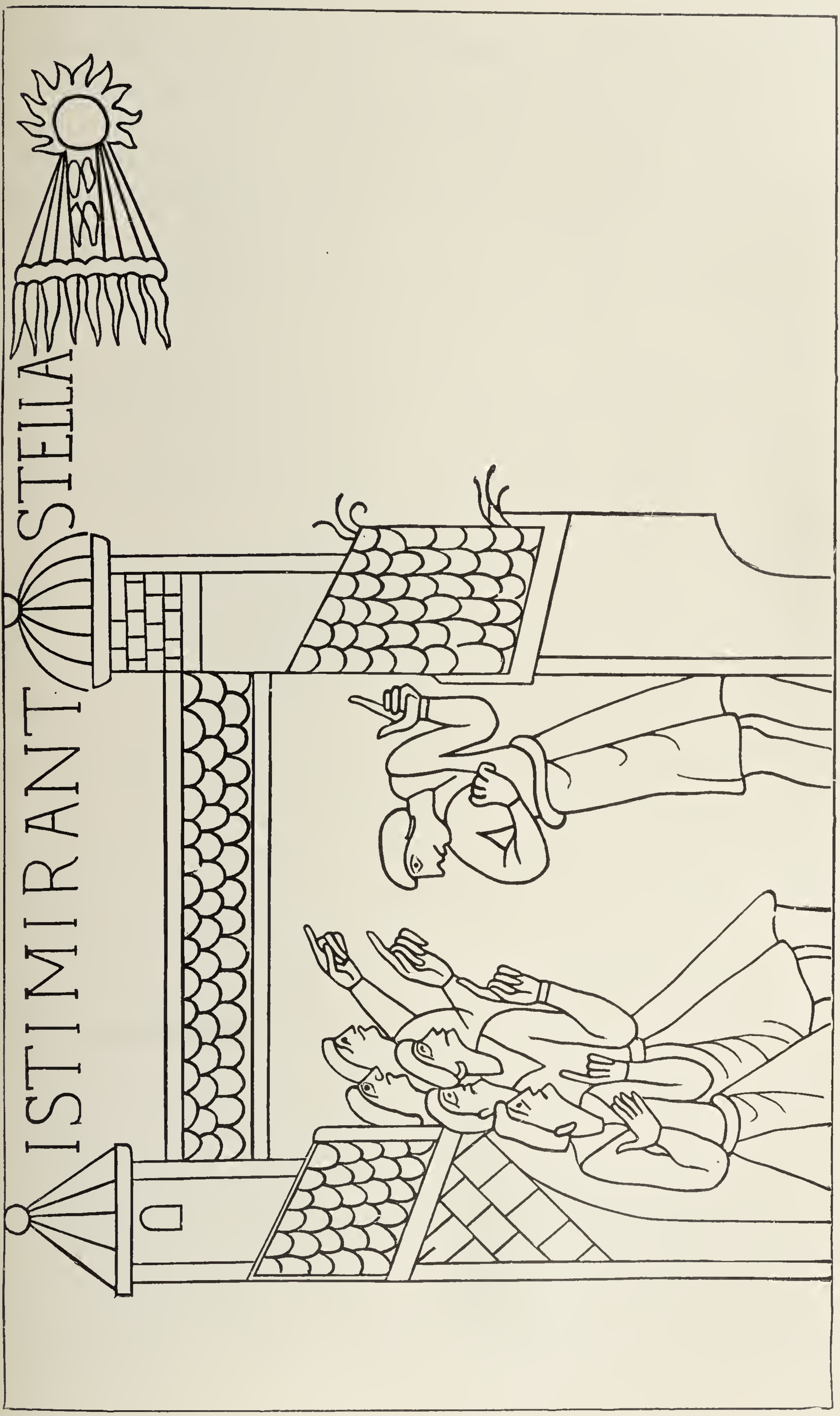
[n] *Month. Not. R.A.S.*, vol. x, p. 51, Jan. 1850: *The Comets*, pp. 50–57.

Philip Augustus, King of France. The records are vague and inadequate; and Cowell and Crommelin have given the preference to a comet which was seen in August and September 1222 and which passed its perihelion probably in September. The Waverley Abbey Annalist says that in the months named a fine star of the 1st magnitude, with a large tail, appeared. When first seen it was near the place where the Sun sets in December. The Chinaman Ma-tuoan-lin says that on Sept. 25 it came from η Bootis. The tail was 30 cubits long, and the comet perished in two months. The question of the identification of one of these comets with Halley's is one of the few instances in which Cowell and Crommelin have dissented from Hind's identifications by deciding in favour of the Comet of 1222 in preference to Hind's 1223.

In April and May 1145 the European and Chinese chroniclers record a comet with a tail 10° long, whose course among the stars from the end of April to the beginning of July is stated by Hind to have been perfectly in accord with the computed path of Halley's Comet, supposing the perihelion passage to have taken place about the 3rd week in April. The Chinese accounts seem to speak of the July Comet as being different from the April and May one, but whether this was so or not cannot be determined with any certainty. Hind seemed to regard the two to be one and the same.

In the April of the year 1066, the year in which the Norman Conquest took place, a remarkable comet attracted the attention of all Europe. In England it was viewed with especial alarm and the success of the Norman invasion and the death of Harold were attributed to the comet's baneful influence. Zonares, the Greek historian, in his account of the reign of the Emperor Constantinus Ducas (whose death occurred in May 1067) describes a comet which was as large as the full moon, and at first was without a tail, on the appearance of which, it (which presumably means the head) diminished in size. This transformation accords with the Chinese accounts, which describe the comet's path among the stars in Chinese fashion with great elaboration. The Chinese say that this object was visible for 67 days, after which "the star, the

Plate XII.



HALLEY'S COMET, 1066. (*From the Bayeux Tapestry.*)

Fig. 44.

vapour, and the comet" all disappeared. It seems fairly certain that this was Halley's Comet. At any rate it was immortalised in the famous Bayeux Tapestry, as will be seen from the annexed plate. [Plate XII.]

In 989 a comet was observed in China which is mentioned also by several Anglo-Saxon writers. Burckhardt, the French computer, investigated its orbit and found that the elements bore a considerable resemblance to those of Halley's Comet. The perihelion passage was found to have occurred about Sept. 12.

Halley's Comet certainly appeared in 912, but there were 2 comets in this year and Cowell and Crommelin differ from Hind in the identification, Hind selecting the earlier one and Cowell and Crommelin the later one, which appeared in the autumn.

Halley's Comet should have appeared in 837. There certainly was a comet in this year, but a comparison of the European and Chinese accounts, taken literally, imply that there were 2 comets in this year, one in perihelion in February and the other in April. The latter would seem to have been a most imposing object, but in Hind's opinion it could not have been Halley's Comet. The Chinese records indeed imply that there was a third or even a fourth comet in that year, in the months of June and September, but we need not discuss this question, which probably involves some misconceptions and which does not concern us in discussing Halley's Comet.

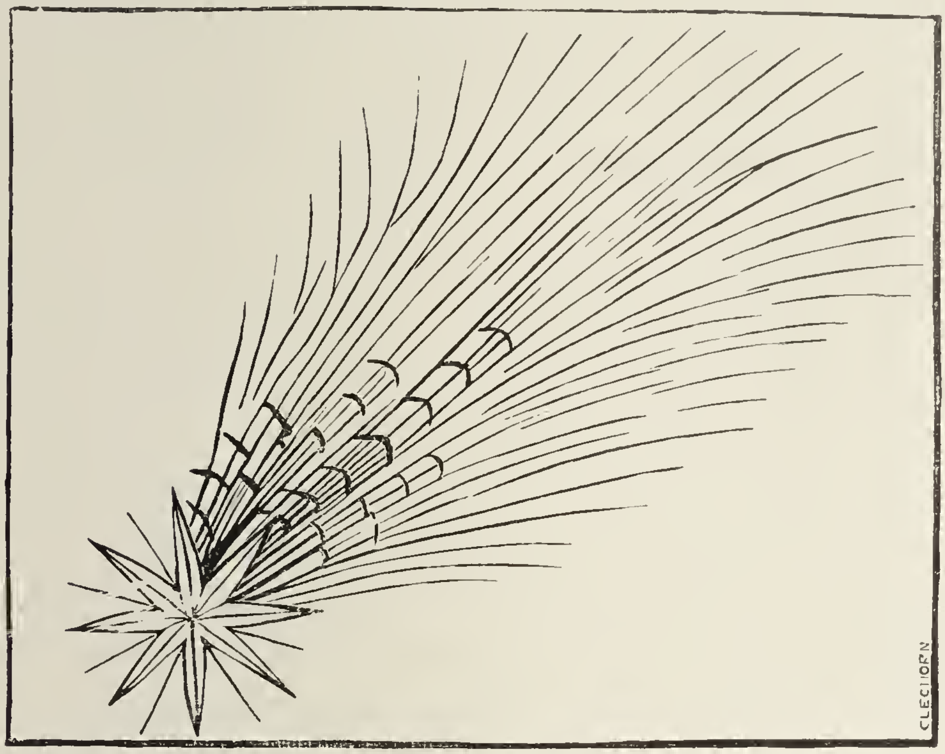
A comet appeared in 760, which without any doubt whatever was Halley's. It is recorded in detail both by European and Chinese annalists, and the orbit has been calculated and identified by Laugier. By European writers we are told that a comet like a great beam and very brilliant was observed in the 20th year of an Emperor Constantine, first in the E. and then in the W., for about 30 days. The Chinese gave it a visibility of 2 months. Laugier calculated the perihelion to have occurred on June 11.

In 684 the Chinese record a comet observed in the W. in September and October. Hind pointed out that this statement would accord with the course of Halley's Comet when

the perihelion occurs about the middle of October, and, as the epoch for the reappearance of the comet is about what it should be, there is "a fair probability" in favour of the identity.

A comet observed by the Chinese in the constellations Auriga, Ursa Major, and Scorpio in 608, was regarded by Hind as probably Halley's, who said that the track assigned

Fig. 45.



HALLEY'S COMET, 684. (*From the Nuremberg Chronicle.*)[o]

would harmonise with a perihelion passage occurring about Nov. 1. Cowell and Crommelin, however, identified the Comet of 607 (i.) as Halley's.

The previous return should have occurred about 530. There was a comet in that year, and none of the few circumstances connected with it recorded by the European chroniclers are

[o] This engraving and Plate XII suggest that mediæval artists were given to "terminological inexactitudes" like many of their successors. As regards Plate XII J. C. Bruce, the editor of *The Bayeux Tapestry elucidated*, says:—"This drawing is remarkable as furnishing us with the earliest representation we have of these bodies." It requires a little interpretation. The picture is supposed to represent Harold in a state of dire alarm on his throne, whilst his people are huddled together pointing with their fingers at the fearful portent in the sky, the birds even being upset at the sight. The legend over the picture "Isti mirant stella" records the popular feeling. Underneath we are asked to take notice of the ships of the invader.

contradictory to the theory which implies that the comet was Halley's. The Chinese records are silent as regards this year.

A comet appeared in 451, as to which there is little doubt that it was Halley's, according to the investigations of Laugier. It was seen in Europe about the time of the celebrated battle of Châlons, when the Roman general Aetius defeated Attila, the leader of the Huns, who had been ravaging central Europe. In China the comet was observed from the middle of May till the middle of July during which period it moved from the Pleiades into Leo and Virgo, a track which agrees with the path which Halley's Comet would have followed if its perihelion passage took place on July 3.

In 373 the Chinese annals record a comet in Ophiuchus in October, which Hind thought would fit in with the probable position of Halley's Comet if the perihelion passage took place about the beginning of November. But another Chinese authority records a comet much earlier in the year, namely in March and April, which must have been visible all through the summer if it were the same as the October comet.

In 295 there was a comet observed in China, the identity of which with Halley's Hind thought to be "nearly certain". It seems to have been visible in May after perihelion passage at the commencement of April.

In the year 218 a large comet is recorded both by European and Chinese chroniclers. Dion Cassius describes it as a very fearful star with a tail extending from the W. towards the E. The Chinese catalogue of Ma-tuan-lin gives it a path exactly in agreement with the path which would be followed by Halley's Comet when the perihelion falls about the first week in April. The description given is that it was "pointed and bright".

In 141 the Chinese observed a comet in March and April, "6 or 7 cubits long" and of a bluish-white colour. The elements of a comet following a path such as that described in some detail by the Chinese annalist would not be widely different from those of Halley's Comet; and the comet is the only one recorded about this epoch.

The preceding apparition should have taken place either

in the summer of 65 or in the following winter of 65–66. The Chinese record 2 comets: one in July 65 which remained visible for 56 days, and the other in February 66 which remained visible 50 days.

Hind suggested that most likely the last-named was Halley's Comet, if the perihelion passage took place at the end of January, and Cowell and Crommelin have definitely confirmed this. Not improbably this comet was the sword-shaped sign recorded as having hung over the city of Jerusalem before the commencement of the war which terminated in the destruction of the Holy City. Josephus says that several prodigies announced the destruction of Jerusalem:—"Amongst other warnings, a comet, of the kind called Xiphias, because their tails appear to represent the blade of a sword, was seen above the city for the space of a whole year[p]." Josephus rebuked his countrymen for listening to false prophets while so notable a sign was in the heavens.

Dion Cassius mentions a comet which seemed to be suspended over the city of Rome before the death of Agrippa. The date would be B.C. 11. The path of this comet was recorded in great detail by the Chinese, and Hind thought that the records afforded "the most satisfactory proof that they belonged to the Comet of Halley". The 3rd week in October was suggested for the perihelion passage. The comet was lost in the Sun's rays 56 days after its discovery.

Cowell and Crommelin have made systematic efforts to trace Halley's Comet back further, and with some success, and it is not beyond the bounds of possibility that further identification will reward research because the Chinese records go back for six centuries before the Christian era, and besides them there exists a sprinkling of European observations, although all these latter are very much lacking both in precision of language and precision of dates.

The danger of jumping at conclusions in the case of astronomy (as indeed in everything else) is painfully shown

[p] *Bella Judæorum*, lib. vi, § 5.

by an article in the *Edinburgh Review* of April 1835 (vol. lxvi, p. 91).

The writer, primed with the knowledge that the period of Halley's Comet was then 75 years, and not knowing that it was not always 75 years, looked through a catalogue of previous comets and ticked off the following, separated by intervals of 75 years or multiples thereof, as apparitions of Halley's Comet, namely: 1456, 1380, 1305, 1230, 1005, 930, 550, 399, 323 A.D. and 130 B.C. We now know that every one of these identifications except the first was wrong! The attraction exercised by the planets was ignored by the writer!

The reader will remember that in anticipation of the return of Halley's Comet, both in 1759 and in 1835, great preparations were made by astronomers for the comet with the view of its being discovered at as early a date as possible, and of learning beforehand its probable path through the heavens. I do not think it can be said that anything like such extensive preparations have been made by mathematical astronomers for the return of 1910; even the date of its perihelion passage has not been predicted as confidently as one might have expected, and certainly might have wished. Seemingly, however, this will occur about the middle of April, and on that assumption, if the comet is discovered as early as December 1909, it will be an evening star up to the beginning of March, about which time it will be lost in the Sun's rays. Passing round the Sun it will reappear on the other side and will become a morning star. It will then be approaching the Earth, and will be nearest to us about May 18. As it will then be in the morning twilight it seems hopeless to expect that we shall see it as the magnificent object which it is evident that our forefathers must have seen at many of its previous apparitions, let alone the unsolved problem whether it is a rule that comets deteriorate in brilliancy after every apparition.[q]

[q] In Appendix IV. there will be found an Ephemeris of the comet for the months, November 1909 to July 1910, calculated partly by Crommelin and partly by D. Smart: to which I have added a statement of

As early as Dec. 22, 1908, an American astronomer, O. J. Lee, at the Yerkes Observatory, Chicago, commenced a photographic search for Halley's Comet. Its then position, according to Seagrave (confirmed by Cowell and Crommelin's independent Ephemeris), was R. A. 6^h 3^m and Decl. 11° 26. As no sign of the anxiously-expected object could be found Lee concluded that it was too small for his telescope, and must have been less bright than a 17^{th} mag. star.

the comet's path among the constellations. Ångström of Upsala in 1862, taking up Hind's identifications, startled astronomers by predicting that the comet would return at a date $2\frac{3}{4}$ years different from the date named by Pontécoulant, namely, April, 1910. (*Nova Acta Societatis Scientiarum Upsaliensis*, vol. iv, N.S., 1863.)

CHAPTER X.

REMARKABLE COMETS.

Suggested list of those which deserve the name.—The Great Comet of 1811.—*The Great Comet of* 1843.—*The Great Comet of* 1858.—*Evidence to enable these three Comets to be compared.—The Great Comet of* 1861.—*The Comet of* 1862 (iii.).—*The Comet of* 1874 (iii.).—*The Comet of* 1880 (i.).—*The Great Comet of* 1882 (iii.).—*Peculiarities of its orbit.—The Comet of* 1887 (i.).—*Sawerthal's Comet of* 1888 (i.).—*The Comet of* 1901 (i.).

THE comets which might be included in a list with the adjective "remarkable" attached to it are very numerous; and I shall for the most part treat the word "remarkable" as applying rather to naked-eye peculiarities and splendour than to physical peculiarities revealed only by the use of the telescope. I must therefore limit myself to a selection, premising that Grant included the following as proper to be classed as "remarkable":—

1066	1531	1682	1823
1106	1556	1689	1835
1145	1577	1729	1843
1265	1607	1744	1858
1378	1618	1759	1861
1402	1661	1769	
1456	1680	1811	

Grant's list was, if I remember right, put forth in a lecture which he gave at the Royal Institution in 1870, and the additions which should be made to it to represent the period 1870–1909 are singularly few, the chief of them being the Comet of 1874 (iii.), best known as Coggia's Comet; and the Comets of 1881 (iii.), and 1882 (iii.); but the large comets which appeared in the Southern hemisphere in 1880 (i.), 1887 (i.), and 1901 (i.) have some claim to notice. By the

law of averages a good bright comet is now more than overdue, and it remains to be seen whether Halley's, when it attains its brightest developement in 1910, will come up to the required standard.

The extravagant language used by the old writers, and the *bizarre* character of the drawings which they have left behind them, render it doubtful how far it is wise to attempt to reproduce either their words or their pictures. I will therefore start no farther back than the middle of the 18th century in my endeavour to present the reader with authentic information and authentic pictures of some comets of special importance.

Although it is commonly considered that Donati's Comet of 1858 (presently to be described) is the most beautiful (though by no means the largest) on record, I cannot help thinking that De Chéseaux's Comet of 1744, with its many and very large tails, should receive the palm for striking beauty. The recorded descriptions of these tails are, however, not very detailed.

This comet was long under a cloud (metaphorically), because nobody seemed inclined to believe that the only drawing and description of it, with its 6 tails, known till recently to be extant, could be true, depending as it was supposed to do on the testimony of one man, and he of no particular astronomical standing, whilst other astronomers of repute mentioned the comet but made no allusion to its many tails. However, all distrust of this man's honesty must now be regarded as unreservedly withdrawn, ample confirmatory testimony having been brought to light as recently as 1864.

The circumstances under which this came about are sufficiently curious. Winnecke, in the year named, unearthed at St. Petersburg some records in MS. by the French astronomer Delisle, in which the fact of this comet having had several tails was clearly stated. He also found in an anonymous pamphlet printed at Berlin in 1744, and edited, it would seem, by the well-known mathematician L. Euler, a very detailed description of the comet and its multiple tail, fully confirmatory of De Chéseaux's account, and written by a

lady member of a well-known German astronomical family, Fräulein Margaretha Kirch.[a]

De Chéseaux has left the following description (translated from the French) of this comet:—

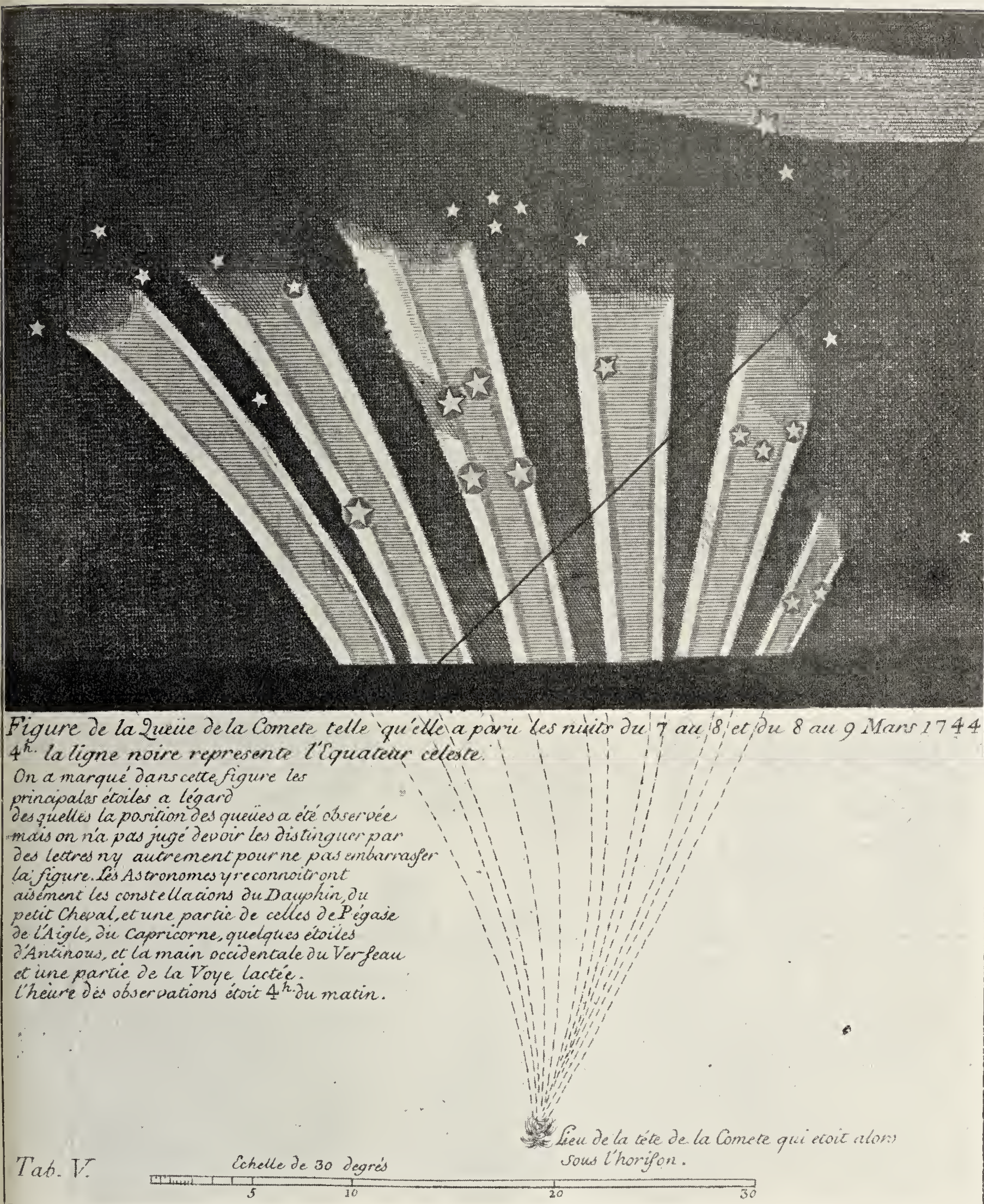
"It appears certain from all the observations up to March 1, that if this comet had appeared under more favourable circumstances, *e.g.* in the middle of a night instead of so near the setting Sun, and also clear of moonlight, it would have been a more striking comet than had ever been known, alike from the size of its head, and from the length of its tail, which up to this time had been simply double; but something much more surprising was in store for us. The sky was quite overcast from the 1st to the 7th of March, but on this last-named day the clouds became broken and gave us some hope of seeing the comet's tail. I prepared myself for seeing over again just about what I had seen during the closing days of February. At 4 o'clock on the morning of March 8, I went downstairs with a friend into the garden with the East facing us. This friend walking in front of me startled me by saying that instead of 2 tails there were 5. I hardly believed him, but after having passed from behind several buildings which had partly concealed the Eastern horizon from me, I did indeed see 5 tails in the form of whitish rays lying one above the other obliquely above the horizon up to a height of 22°, and of about the same breadth in all. These rays were each about 4° in width, but they became narrower towards their lower extremities. Their edges were sufficiently distinct and rectilinear. Each ray was made up of 3 bands; the middle one was darker, and double the width of the bands forming the edges. These last named resembled precisely the brightest portions of the Milky Way between Antinoüs and Sagittarius, and between Ophiuchus and Scorpio. The interval between the chief rays was dark like the rest of the sky; however, at the bottom there was some luminosity resembling that at the extremity of these rays, as if we were looking at the tips of other rays of shorter length.[b] Besides these 5 tails edged by white bands there was a sixth in which one noticed no bands, perhaps because it was low down. This sixth tail joined to the 10 brighter bands of the others presented the appearance of there being 11 rays in all[c]."

De Chéseaux goes on to make some comments which seem rather intended as a reply to certain persons who had criticised unfavourably the idea that the object which they had been looking at was really a comet. After referring

[a] All this story is fully set out by J. W. L. Dreyer in the *Copernicus* Magazine, vol. iii, p. 104, 1884, accompanied by diagrams.

[b] This surmise was founded on fact, for the picture given by the writer quoted above in *Copernicus* shows clearly that there were several minor tails besides De Chéseaux's 5.

[c] These details do not quite harmonise, it will be noticed, with the engraving, but they appear to belong to the date of March 7–8, whilst the engraving appears intended to apply to 2 nights combined.



THE GREAT COMET OF 1744. March 7.

(Drawn by De Chéseaux.)

P. 128.

to the fact that 18 persons had seen the comet at Lausanne and several at Berne, but that bad weather had prevented any observations at Geneva or Paris, he says:—"Astronomers must judge for themselves whether the phenomenon described was that of a celestial body; and if it could have been possible that any merely atmospheric phenomenon could have maintained steadily during 24 hours its condition unchanged, its size and colour the same, its position with respect to the fixed stars the same, and have participated with them in the diurnal movement." De Chéseaux reckons his 24 hours from the night of March 7–8 to the following night of March 8–9, after which he never saw the comet again. He adds that "the sky was very serene without the least cloud or haze, and that both Sun and Moon, (to one or other of which only could the phenomenon be ascribed if it was only atmospheric,) were both of them too far away from the point of convergence of the tails." He then offers some further remarks directed to show that if the rays were tails of a comet, which had its head below the horizon, everything would be explained satisfactorily.

The Comet of 1811 (i.) is one of the most celebrated of modern times.[d] It was discovered by Flaugergues at Viviers on March 26, 1811, and was last seen by Wisniewski at Neu-Tscherkask in the south of Russia on Aug. 17, 1812, a visibility of 17 months—a period then unprecedented. It was a result of this long visibility that, owing to the Earth's annual motion, the comet twice disappeared in the Sun's rays, and twice reappeared after having been in conjunction with the Sun. In the autumnal months of 1811 it shone very conspicuously with a bright nucleus and tail, which became visible soon after sunset and continued visible throughout the night for many weeks, owing to its high northern declination. The extreme length of the tail is dated for the 1st week in October, and was about 25°, with a breadth of about 6°.

[d] This comet attracted the attention of Napoleon in connection with his invasion of Russia, and divers omens were drawn from it. (See p. 205, *post.*)

Previously to this, in August, the tail, according to Bouvard, was divided into two branches which were nearly at a right angle to each other. Sir W. Herschel paid particular attention to this comet, and his observations are of great value. He states that it had a well-defined planetary disc by way of nucleus, which was involved in the nebulosity forming the head. From this measurement he calculated that the diameter

Fig. 47.

THE GREAT COMET OF 1811.

of the nucleus was 428 miles. When examined with high powers the stellar character of the nucleus disappeared, and the light was spread, though not uniformly. The nucleus had a ruddy hue, but the surrounding nebulosity was of a bluish-green tinge.[e] The real length of the tail about the middle of Oct. was upwards of 100,000,000 miles, and its breadth about

[e] *Phil. Trans.*, vol. cii, pp. 118, 119, 121. 1812.

15,000,000 miles. This comet is undoubtedly a periodical one. Argelander, whose investigation of the orbit is the most complete, assigned to it a period of 3065 years, subject to an uncertainty of only 43 years.[f] The aphelion distance is 14 times that of Neptune, or, say, 40,000,000,000 miles.

The comet of 1811 obtained in Western Europe, and especially in Great Britain, fame of a very un-astronomical character. Its year of appearance was also the year of an unusually celebrated port wine vintage in Portugal, and "Comet Wine" figured for a long period of years, first of all in the price-lists of wine merchants, and afterwards in the cellar books of many private houses, and finally in the advertisements of auction sales. The last such advertisement which I remember to have seen appeared in the *Times* somewhere in the "Eighties", so the wine and the label thereof lasted long.

The Comet of 1843 (i.) was another very celebrated comet, and I once came upon the following remarks made by one who had seen Donati's Comet of 1858, as well as that of 1843, and was able to compare the one with the other. General J. A. Ewart wrote thus of the comet of 1843:—

> "It was during our passage from the Cape of Good Hope to the Equator, and when not far from St. Helena, that we first came in sight of the great comet of 1843. In the first instance a small portion of the tail only was visible, at right angles to the horizon; but night after night as we sailed along, it gradually became larger and larger, till at last up came the head, or nucleus, as I ought properly to call it. It was a grand and wonderful sight, for the comet now extended the extraordinary distance of one-third of the heavens, the nucleus being, perhaps, about the size of the planet Venus."[g]

General Ewart thus speaks of Donati's Comet of 1858, which will be described on a later page:—

> "A very large comet made its appearance about this time, and continued for several weeks to be a magnificent object at night; *it was, however, nothing to the one I had seen in the year 1843*, when on the other side of the Equator."

Writing from the Cape of Good Hope on Nov. 12, 1843,

[f] *Berlin. Ast. Jahrbuch*, 1825, p. 250.

[g] *The Story of a Soldier's Life*, vol. i, p. 75.

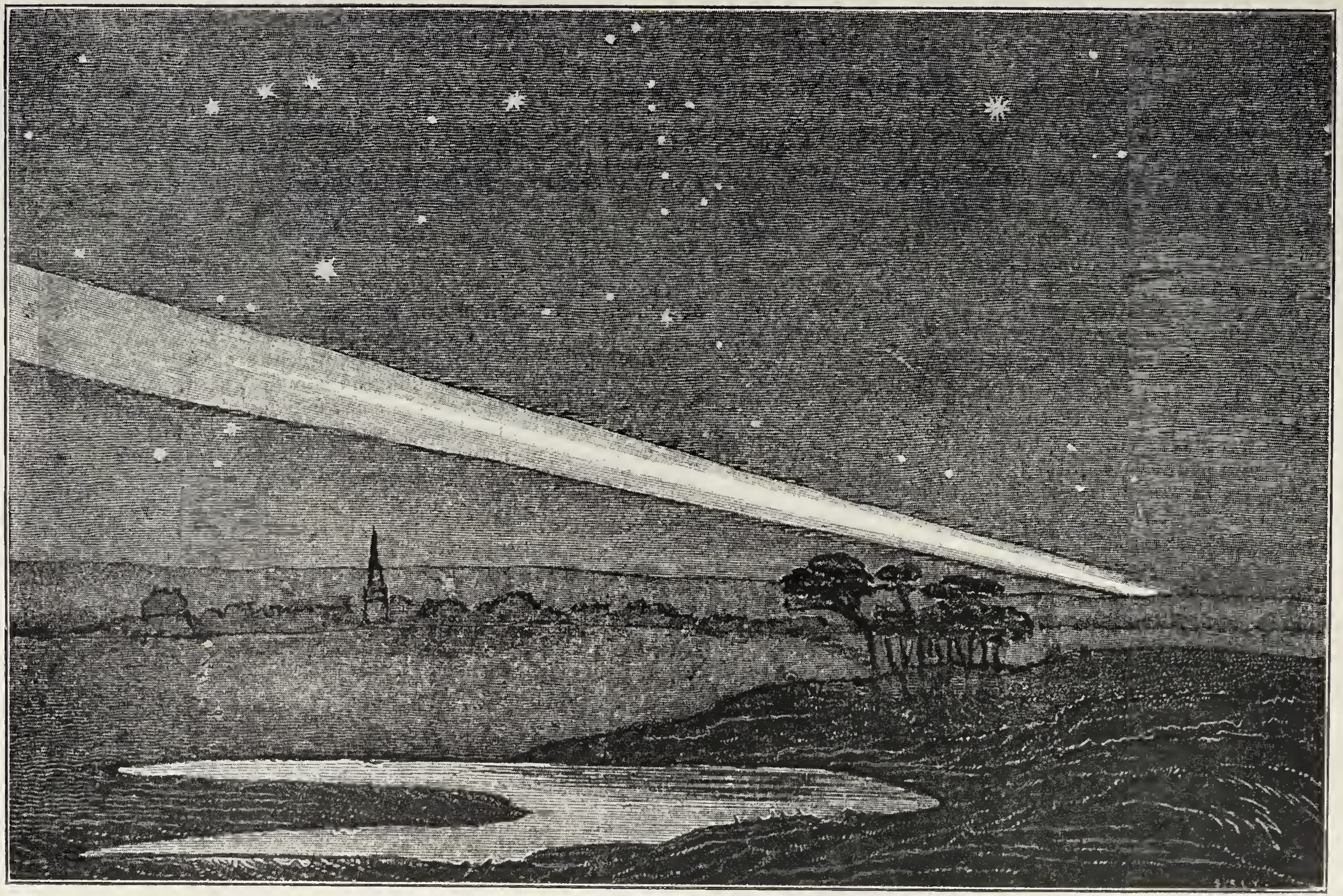
to his friend Admiral Smyth, Mr. (afterwards Sir Thomas) Maclear said :—

"Of the casual observatory phenomena, the grand Comet of March takes precedence; and few of its kind have been so splendid and imposing. I remember that of 1811: it was not half so brilliant as the late one."

So far as I know this is the only account which has ever appeared in print, written by one who had had the chance of seeing both comets, and was capable of scientifically appraising them. Sir John Herschel would have seen all three of these bodies (1811, 1843, 1858), but he does not appear to have left behind him any remarks on the earliest one. This may not be extraordinary, seeing that he was only an Undergraduate at Cambridge, and only aged 19 when the comet appeared, and that he did not start his astronomical career until 5 years afterwards. The Comet of 1843 was first seen in the Southern Hemisphere in the last week of February, but nobody can be named as its first discoverer, because it displayed itself suddenly, and was seen by a multitude of persons. During the first fortnight in March it shone with great brilliancy, and the journals of Australian and New Zealand colonists make many allusions to it. It was not visible in England until after March 15, when its splendour had much diminished, but the suddenness with which it made its appearance to observers in the Northern Hemisphere, as it had done in the Southern, added not a little to the interest which it excited.[h] The general length of the tail during March, as seen in the Northern Hemisphere, was about 40°, and its breadth about 1°.

The orbit of this comet is remarkable for its small perihelion distance, which according to the most trustworthy calculation did not exceed about 500,000 miles; and the immense velocity of the comet in its orbit when near perihelion occasioned some extraordinary peculiarities. Thus, between February 27 and February 28 it described upon its orbit an arc of no less than 292°. Assuming its true orbit to be elliptical, as we are entitled to do, this would leave

[h] Be it remembered that in those days there were no submarine telegraph cables to convey warning of things that were going to happen.



THE GREAT COMET OF 1843. March 17.

AS SEEN FROM BLACKHEATH, KENT.

P. 132.

DONATI'S COMET: OCTOBER 5, 1858.
(*Drawn by Pape.*)

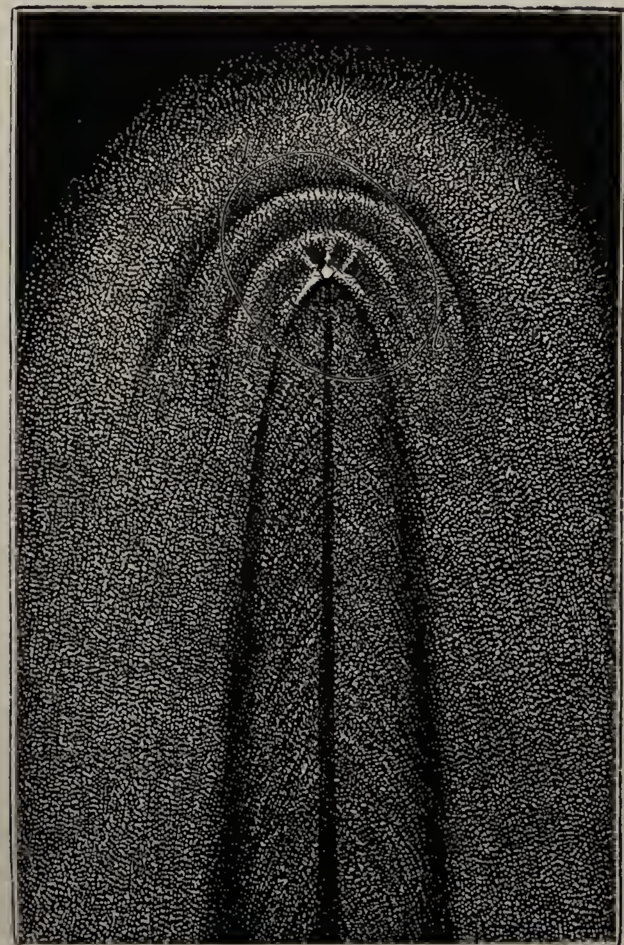
only 68° to be described during the time which would elapse before its next return to perihelion. Various attempts have been made, without any very definite measure of success, to identify this comet with others which have gone before; but this is a matter which belongs to a previous chapter.[1]

The Comet of 1858 (vi.). On June 2 in that year G. B. Donati, of Florence, descried a faint nebulosity slowly advancing towards the North, and near the star λ Leonis. Owing to its immense distance from the Earth (something like 240,000,000 miles) great difficulty was experienced in laying down its orbit. By the middle of August, however, its future course, and the great increase in its brightness which would take place in September and October, were clearly foreseen. Up to August it had remained a faint object, not discernible by the unaided eye. It was distinguished from ordinary telescopic comets only by the extreme slowness of its motion (in singular contrast to its subsequent career), and by the vivid light of its nucleus. It has well been said that "the latter peculiarity was of itself prophetic of a splendid destiny". Traces of a tail were noticed on August 20, and on August 29 the comet was faintly perceptible to a keen unaided eye, but it was not until Sept. 3 that I so saw it. For a few weeks the comet occupied a Northern position in the Heavens, and it was therefore seen both in the morning and in the evening. On Sept. 6 a slight curvature of the tail was noticed, which subsequently became one of its most striking features. On Sept. 17 the head equalled in brightness a star of the 2nd mag., the length of the tail being 4°. The comet passed its perihelion on Sept. 29, and was at its least distance from the Earth on Oct. 10. Its rapid passage to the Southern Hemisphere rendered it invisible in Europe after the end of October, but it was followed at the Santiago-de-Chili and Cape of Good Hope Observatories for some months afterwards, being last seen by Sir T. Maclear at the latter place on March 4, 1859." Its early discovery enabled Astronomers, while it was yet

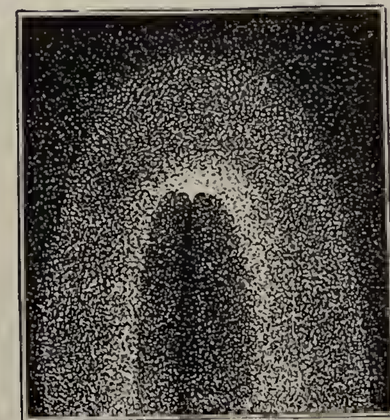
[1] See p. 19 (*ante*). Reference should also be made to E. J. Cooper's *Cometic Orbits*, pp. 159 69.

DONATI'S COMET: OCTOBER 9, 1858.
(Drawn by Pape.)

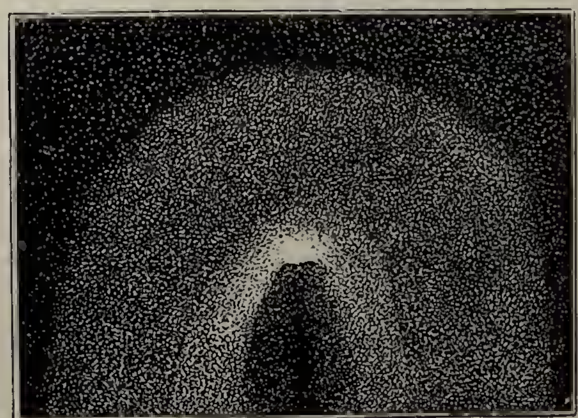
September 22. (*Pape.*)



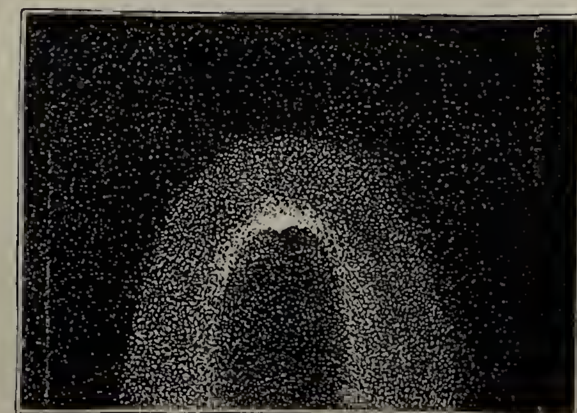
(*Anon.*)



September 29. (*Pape.*)



October 6. (*Pape.*)



October 12. (*Pape.*)

DONATI'S COMET, 1858: VIEWS OF THE COMA.

scarcely distinguishable in the telescope, to predict, some months in advance, its approaching brilliancy, and thus the comet was observed with all the advantage of previous preparation and anticipation. "The perihelion passage occurred at the most favourable moment for presenting the comet to good advantage. When nearest the Earth the direction of the tail was nearly perpendicular to the line of vision,

Fig. 56.

DONATI'S COMET, 1858, SEPT. 30. (*Smyth.*)

so that its proportions were seen without foreshortening. Its situation in the latter part of its course afforded also a fair sight of the curvature of the train, which seems to have been exhibited with unusual distinctness, contributing greatly to the impressive effect of a full-length view." This comet, though surpassed by many others in size, has not often been equalled in the intense brilliancy of its nucleus,

and the unusual, and, so to speak, artistic conformation of its tail, which features the absence of the Moon in the early part of October enabled spectators to view to the very best advantage. The passage of the comet in front of Arcturus on Oct. 5 will ever remain treasured in the memory of those

Fig. 57.

DONATI'S COMET, 1858, PASSING ARCTURUS ON OCT. 5.

who saw it. There is no doubt that Donati's Comet revolves in an elliptic orbit, the period of which has been variously estimated at 1879, 2040, and 2138 years, and Kritzinger thinks it may be identical with a great comet which is recorded by Seneca as having appeared in B.C. 146, and dated by the Chinese for the month of August in that year.

The following is a table of the dimensions[k] of the comet's nucleus and tail, at the undermentioned dates[l]:—

Date.	Diameter of Nucleus.		Length of Tail.	
1858.	″	Miles.	°	Miles.
July 19	5	= 5600		...
Aug. 30	6	= 4660	2	= 14,000,000
Sept. 8	3	= 1980	4	= 16,000,000
,, 12	...		6	= 19,000,000
,, 23	3	= 1280	5	= 12,000,000
,, 25	...		11	= 17,000,000
,, 27	...		13	= 18,000,000
,, 28	...		19	= 26,000,000
,, 30	...		22	= 26,000,000
Oct. 2	...		25	= 27,000,000
,, 5	1·5	= 400	33	= 33,000,000
,, 6	3·0	= 800	50	= 45,000,000
,, 8	4·4	= 1120	50	= 43,000,000
,, 10	2·5	= 630	60	= 51,000,000
,, 12	...		45	= 39,000,000

The head of Donati's Comet deserves some special description because of the changes which it underwent and which have already been mentioned[m] as features which often characterise very large comets. Bond first noticed, on Sept. 20, envelopes, 2 in number, above the nucleus, the outer one at a distance of 16″ above the nucleus, and the inner one about 3″. The outer one disappeared on Sept. 30 at the height of about 1′. Meanwhile a third had appeared, the one originally second having gradually expanded so as to take the place of the first. Seven successive envelopes in all were seen to rise from the comet, the last one starting on Oct. 20, when all the others had been dissipated. It was calculated that the

[k] These measurements must be read in the light of the caution given in footnote [a] on p. 222 (*post*).

[l] G. P. Bond, *Math. Month. Mag.*, Boston, U.S., Nov. and Dec. 1858. Bond subsequently published a magnificent volume of notes and pictures relating to this comet forming vol. ii of the *Annals of the Harvard College Observatory*, Cambridge, Mass., 1862.

[m] See p. 30 (*ante*).

THE GREAT COMET OF 1861, ON JUNE 30.
(*Drawn by G. Williams.*)

envelopes moved upward at the general rate of something like 30 miles an hour. The first one rose to a height of about 18,000 miles, when it wasted away; but none of the others reached so far, disappearing at elevations lower and lower, the last being lost sight of at an elevation of about 6000 miles.

It has been calculated that at perihelion Donati's Comet travels at a speed of 30 miles a second; but that at aphelion its speed is only 234 yards a second.

Few comets excited greater sensation by their sudden appearance above the horizon than the great Comet of 1861 (No. ii. of that year). It was discovered by J. Tebbutt, an amateur astronomer, at Windsor, N.S.W., on May 13, previous to its perihelion passage, which took place on June 11. Passing from the Southern Hemisphere into the Northern, it became visible in this country on June 29, though it was not generally seen until the following evening. It is so rare for the inhabitants of the British Islands to have a big comet all their own, as it were, that in this case the multitude of observers and observations was so great that selection is difficult.[n]

A good all-round description was that given by Sir John Herschel, who observed the comet at his house, "Collingwood," Hawkhurst, Kent. He says:—

"The comet, which was first noticed here on *Saturday* night, June 29, by a resident in the village of Hawkhurst (who informs me that his attention was drawn to it by its being taken by some of his family for the Moon rising), became conspicuously visible on the 30th, when I first observed it. It then far exceeded in brightness any comet I have before observed, those of 1811 and the recent splendid one of 1858 not excepted. Its total light certainly far surpassed that of any fixed star or planet, except perhaps Venus at its maximum. The tail extended from its then position, about 8° or 10° above the horizon, to within 10° or 12° of the Pole-star, and was therefore about 30° in length. Its greatest breadth, which diminished rapidly in receding from the head, might be about 5°. Viewed through a good achromatic, by Peter Dollond, of $2\frac{3}{4}$-inches aperture and 4-feet focal length, it exhibited a very condensed central light, which might fairly be called a nucleus; but, in its then low situation, no other physical peculiarities could be observed. On the 1st instant it was seen early in the evening,

[n] By far the most complete account is that by the Rev. T. W. Webb in the *Month. Not. R. A. S.*, vol. xxii, p. 305. 1862.

but before I could bring a telescope to bear on it clouds intervened, and continued till morning twilight. On the 2nd (Tuesday), being now much better situated for observation, and the night being clear, its appearance at midnight was truly magnificent. The tail, considerably diminished in breadth, had shot out to an extravagant length, extending from the place of the head above o of the Great Bear at least to π and ρ Herculis; that is to say, about 72°, and perhaps somewhat further. It exhibited no bifurcation or lateral offsets, and no curvature like that of the Comet of 1858, but appeared rather as a narrow prolongation of the Northern side of the broader portion near the comet than as a thinning off of the latter along a central axis, thus imparting an unsymmetrical aspect to the whole phenomenon.

"Viewed through a 7-feet Newtonian reflector of 6-inches aperture the nucleus was uncommonly vivid, and was concentrated in a dense pellet of not more than 4″ or 5″ in diameter (about 315 miles). It was round, and so very little *woolly* that it might *almost* have been taken for a small planet seen through a dense fog; still so far from *sharp* definition as to preclude any idea of its being a solid body. No sparkling or star-light point could, however, be discerned in *its* centre with the power used (96), nor any separation by a darker interval between the nucleus and the cometic envelope. The gradation of light, though rapid, was continuous. Neither on this occasion was there any *unequivocal* appearance of that sort of fan or sector of light which has been noticed on so many former ones.

"The appearance of the 3rd was nearly similar, but on the 4th the fan, though feebly, was yet certainly perceived; and on the 5th was very distinctly visible. It consisted, however, not in any vividly radiating jet of light from the nucleus of any well-defined form, but in a crescent-shaped cap formed by a very delicately graduated condensation of the light on the side towards the Sun, connected with the nucleus, and what may be termed the *coma* (or spherical haze immediately surrounding it), by an equally delicate gradation of light, very evidently superior in intensity to that on the opposite side. Having no micrometer attached, I could only estimate the distance of the brightest portion of this crescent from the nucleus at about 7′ or 8′, corresponding at the then distance of the comet to about 35,000 miles. On the 4th (Thursday) the tail (preserving all the characters already described on the 2nd) passed through α Draconis and τ Herculis, nearly over η and ϵ Herculis, and was traceable, though with difficulty, almost up to α Ophiuchi, giving a total length of 80°. The northern edge of the tail, from α Draconis onwards, was perfectly straight,—not in the least curved,—which, of course, must be understood with reference to a great circle of the heavens.

"Viewed, on the 5th, through a doubly refracting prism well achromatised, no certain indication of polarisation in the light of the nucleus and head of the comet could be perceived. The two images were distinctly separated, and revolved round each other with the rotation of the prism without at least any marked alternating difference of brightness. Calculating on Mr. Hind's data, the angle between the Sun and Earth and the comet must then have been 104°, giving an angle of incidence equal to 52°, and obliquity 38°, for a ray supposed to reach the eye *after a single* reflection from the cometic matter. This is not an angle unfavourable to polarisation, but

July 8. (*Webb.*)

July 2. (*Brodie.*)

July 2. (*Brodie.*)

(*Chambers.*)

THE GREAT COMET OF 1861.

the reverse. At 66° of elongation from the Sun (which was that of the comet on the occasion in question), the blue light of the sky is very considerably polarised. The constitution of the comet, therefore, is analogous to that of a cloud ; the light reflected from which, as is well known, at that (or any other) angle of elongation from the Sun, exhibits no signs of polarity."

Williams's drawing of the Comet of 1861, reproduced in Plate XVIII, gave a much more extensive and complex character to the comet's tail than any of the other drawings published.

A very interesting point was raised by Hind, and developed, so to speak, by E. J. Lowe, the well-known meteorologist. Hind stated that he thought it not only possible, but even probable, that in the course of Sunday, June 30, the Earth passed through the tail of the comet at a distance of perhaps $\frac{2}{3}$rds of its length from the nucleus. The head of the comet was in the Ecliptic at 6 p.m. on June 28, at a distance from the Earth's orbit of about 13,000,000 miles on the inside, its heliocentric longitude (its longitude seen from the centre of the Sun) being 279°. The Earth at that moment was rather more than 2° behind that point, but would arrive there soon after 10 p.m. on June 30. The tail of a comet is seldom an exact prolongation of the radius vector, or imaginary line joining the nucleus with the Sun; towards its extremity a tail is almost invariably curved; or, in other words, the matter composing it lags behind what would be its position if it travelled with the same speed as the nucleus. Now judging from the amount of curvature on June 30, and the direction of the comet's motion, Hind thought that the Earth very probably encountered the tail in the early part of that day; or, at any rate, that it was certainly in a region which had been swept over by cometary matter a short time previously. He added that on the evening of June 30 there was a peculiar phosphorescence or illumination of the sky which he attributed at the time to an auroral glare. It was remarked by other persons as something unusual; and it seems scarcely open to doubt that the Earth's proximity to the comet had something to do with it. Lowe confirmed Hind's statement of the sky

having a peculiar appearance on the evening of June 30. He says that the sky had a yellow, auroral, glare-like look; and that the Sun, though shining, gave but a feeble light. The comet was plainly visible during sunshine at 7.45 p.m. In confirmation of the statement that there was something unusual and indescribable happening, Lowe adds that in his parish church the vicar had the pulpit candles lighted at 7 o'clock, which proves that some sensation of darkness was felt even while the Sun was shining. Though unaware at the time that the comet's tail was enveloping the Earth, he was so struck by the singularity of what he saw that he made the following entry in his day-book:—"A singular yellow phosphorescent glare, very like diffused Aurora Borealis, yet, being daylight, such Aurora could scarcely be noticeable." The comet itself, he states, had a much more hazy appearance than on any subsequent evening.

De La Rue attempted to photograph the comet, but it left no impressions on 2 collodion plates, although neighbouring stars did impress themselves on the plates.

No fewer than 11 envelopes were seen to spring from the head of this comet between July 2, when portions of 3 were in sight, and July 19; a new one rising at regular intervals every second day. And their evolution and dispersion took place with much greater rapidity than was the case with Donati's Comet in 1858; each envelope taking but 2 or 3 days to go through its various changes instead of 2 or 3 weeks.

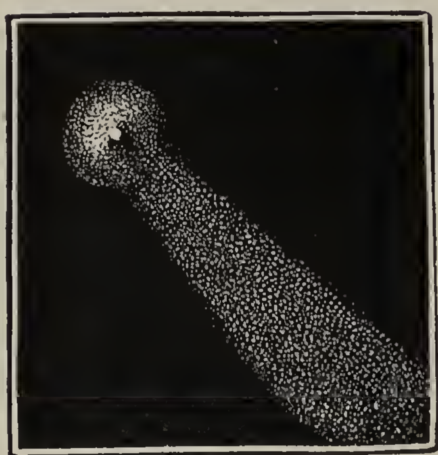
On the question of the polarisation of the light of the comet, Secchi said:—

"The most interesting fact I observed was this: the polarisation of the light of the comet's tail and of the rays near the nucleus was very strong, and one could even distinguish it with the band polariscope; but the nucleus presented no trace of polarisation, not even with Arago's polariscope with double coloured image. On the contrary, on the evenings of July 3, and following days, the nucleus presented decided indications, in spite of its extreme smallness, which, on the evening of July 7, was found to be hardly 1″.

"I think this a fact of great importance, for it seems that the nucleus on the former days shone by its own light, perhaps by reason of the incandescence to which it had been brought by its close proximity to the Sun.

Aug. 7.

Aug. 18.



Aug. 18.

Aug. 19.

Aug. 22.

Aug. 29.

THE COMET OF 1862 (iii.).

(*Drawn by Challis.*)

"During the following days the tail has been constantly diminishing, but it is remarkable that it has always passed near to α Herculis, and that it reached to the Milky Way up to July 6. It would seem that the two tails were nearly independent, and that on July 5 the length and straightness had gone off from the large one, and that this bent itself to the southern side. Last night (July 7) the long train was hardly perceptible. The light was polarised in the plane of the tail."

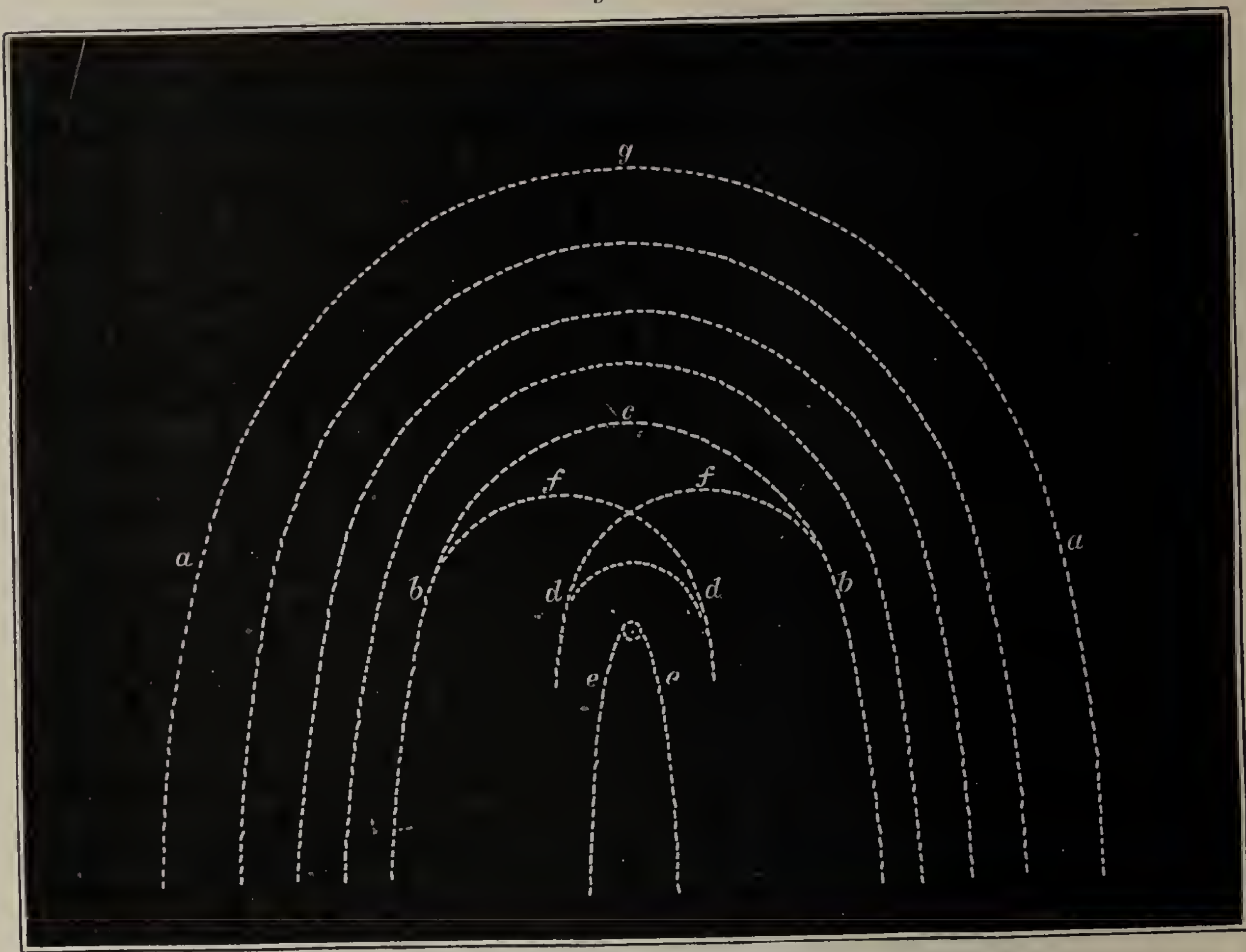
Observations on the polarisation of the light of the comet were also made by Poey at Passy, near Paris. He found that "the plane of polarisation seemed to pass sensibly perpendicular to the axis of the tail". Poey had in 1858 observed Donati's Comet for polarisation, and found that its light was polarised in a plane passing through the Sun, the comet, and the observer.

The Comet of 1862 (iii.), though not one of first-class magnitude or brilliancy, was nevertheless a very interesting object on account of the fact that a jet of light, frequently altering in form, was observed for a long time to emanate from its nucleus. Jets of light shooting forth under such circumstances are not uncommon, as we have already seen, but in the case of this particular comet there seemed an unceasing supply thrown out from the nucleus without any material deterioration of the luminosity of the source of supply. It need hardly be added that the late Professor Challis, to whom we owe the annexed drawings, was a skilful and experienced observer. This comet had a tail which on Aug. 27 was 20° long.

The Comet of 1874 (iii.), discovered by Coggia at Marseilles, was one of considerable interest. The drawing from which Plate XX. has been engraved (and of which Fig. 69 is a skeleton outline) was made with an achromatic telescope of 8½ inches aperture and 11½ ft. focal length, on July 13, the most favourable night of all for a careful scrutiny of the comet, when its position in the heavens, its proximity to the earth, and the absence of twilight, 3 favourable circumstances, are jointly taken into consideration. The southerly motion of the comet was so rapid that on July 14 the presence of twilight greatly interfered with the visibility of the details shown in the drawing. The following description is from the pen of F. Brodie:—

"The head of the comet presented the great peculiarity of having two eccentric envelopes in addition to the ordinary bright envelope immediately surrounding the nucleus. The first envelope was a bright and sharply defined semi-circle surrounding the nucleus: the two eccentric envelopes were nearly as bright, and also very sharply defined, also semi-circular, having their centres placed (about) on the edge of the first envelope, and

Fig. 69.



COGGIA'S COMET OF 1874.

Skeleton outline on July 13. (*Brodie.*)

a, g, a. Undefined outline of nebulous head.
b, c, b. Fairly defined outline of second envelope.
d, d. Sharply defined outline of first envelope, semi-circular, and very bright.
e, e. Very sharply defined clear dark space between bifurcation of tail, free from nebulosity.
f, f. Singular eccentric envelopes, sharply defined, fading away at and into *b b*. The centres of those envelopes were at *d*.
g, c. Between these two points several envelopes concentric with *d d* were traceable.

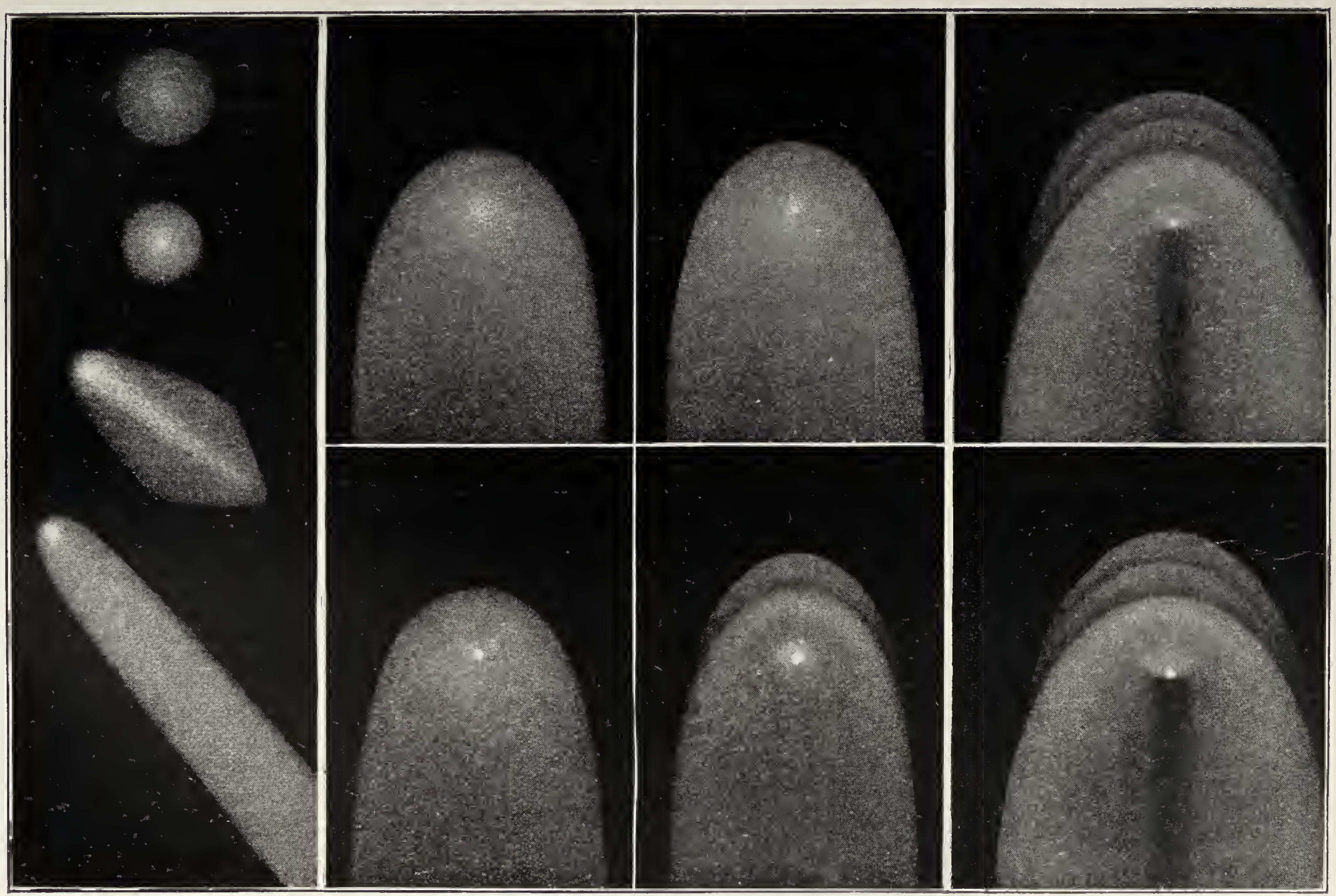
intersecting each other. The second centrical envelope just embraced both these eccentric envelopes, and was about half the width of the nebulous head of the comet. Between this second envelope and the ill-defined outline of the head (that is, between *c* and *g*) there were faintly marked outlines of other concentric envelopes. The nucleus, which, according to Hind, was 4000 miles in diameter, appeared to be somewhat flattened on

COGGIA'S COMET, 1874: ON JULY 13.
(*Drawn by Brodie.*)

the side opposite to the Sun. From this side also the head of the comet divided itself into two distinct parts forming the commencement of the tail: for some distance this bifurcation was remarkably sharply defined, suggesting an intense repulsive force acting upon the nucleus of the comet; and the space enclosed between this bifurcation was strikingly free from nebulous matter, until at some little distance away from the nucleus the sharp definition faded into the general nebulosity of the tail."

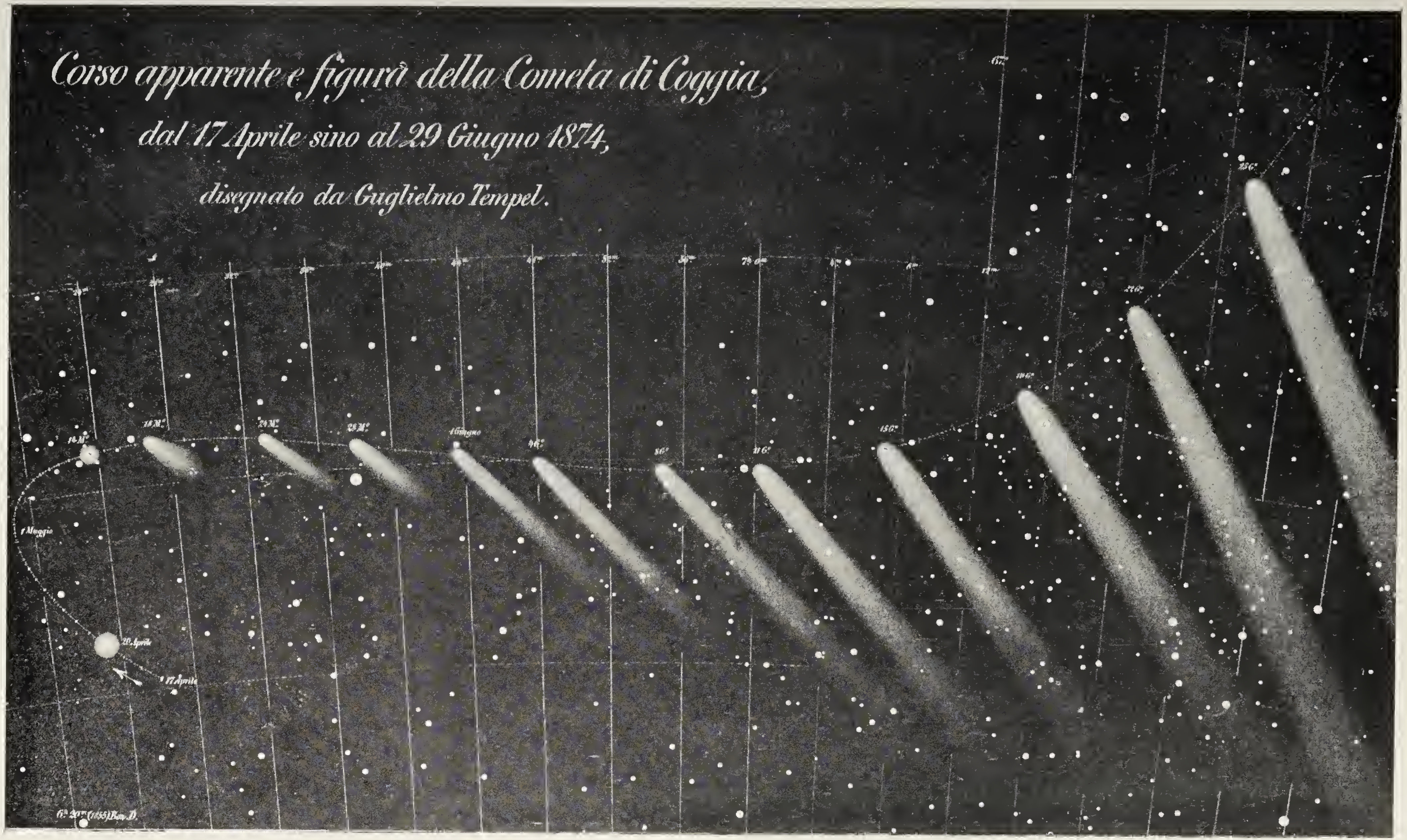
The following remarks on this comet are by two French observers, MM. Wolf and Rayet:—

"After having maintained for many days a great sameness of form, on June 22 a series of changes in the shape of the head of the comet commenced. On that day the comet, viewed with a Foucault telescope of 40 centimetres, appeared to be enclosed in the interior of a very elongated parabola. Starting from the nucleus, which was placed as it were at the focus of the curve, the brightness decreased gradually towards the summit: but in the interior of the parabola the diminution of the brightness was sudden, and the boundary-line exhibited another parabola a little more open than the first, and having at its own summit the brilliant nucleus itself. The outline of the parabola which passed through the nucleus was prolonged so as to form the lateral boundaries of the tail, the edges of which were well defined and were much brighter than the interior parts. This tail had then the appearance of a luminous envelope hollow in the inside. The nucleus was always very sharp. On July 1 the general form of the comet remained the same; it appeared always to possess a parabolic outline at its exterior edge. The nucleus, however, jutted out into the interior of the second parabola, and the opposite margins of the tail were not strictly symmetrical. The West side, that is to say the side which had the greatest R.A., was very sensibly brighter than the other. . . . From July 5, the want of symmetry spoken of above became more and more marked, and near the head the decrease of the brightness became less regular. On July 7, the contrast between the two branches was striking, the Western branch of the tail being about twice as bright as the Eastern. At the same time the nucleus appeared to be becoming diffused, and it seemed to fade away in the direction of the head of the comet, although still sharply defined on the side nearest the tail; one could not fail to remark its resemblance to an open fan. . . . Our last observation of the comet was made on July 14 at 9.30 p.m.: important changes in the aspect of the head had manifested themselves. The fan of light had disappeared on the West side, and was replaced by a long spur of light which was traceable for a considerable distance across the head; on the West side the remnant of the fan terminated abruptly, and the boundary-line there made but a small angle with the main axis of the comet. On this same occasion two rays of light were visible—two jets as they might be deemed—thrown forwards, the one to the right and the other to the left; these luminous rays seemed to have their origin at the edge of the fan of which they formed a sort of prolongation. The ray which pointed towards the East projected well forwards, and being bent round towards the tail soon reached the preceding edge of the comet; it was faint and hardly surpassed the nebulosity in brilliancy. The ray projected towards the West was much more brilliant, and was similarly



COGGIA'S COMET OF 1874 (iv.).

SUCCESSIVE CHANGES BETWEEN APRIL 20 AND JULY 8. *(Drawn by W. Tempel.)*



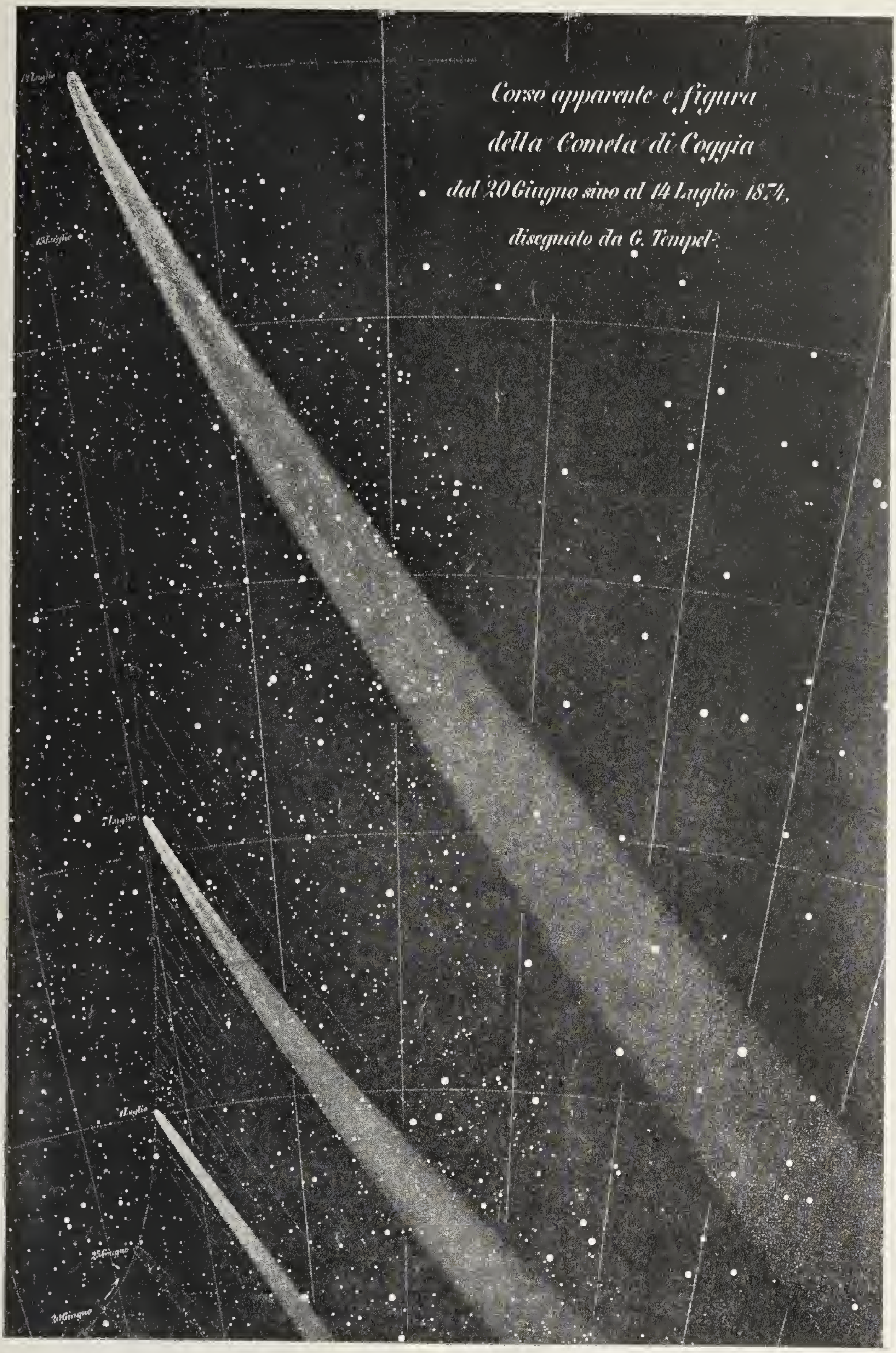
COGGIA'S COMET OF 1874 (iv.).

PATH AND DEVELOPEMENT BETWEEN APRIL 20 AND JUNE 25; DATE OF PERIHELION PASSAGE, JULY 17.

(*Drawn by W. Tempel.*)

P. 150 b.

Fig. 82. *Plate* XXIII.



COGGIA'S COMET OF 1874 (iv.).

PATH AND DEVELOPEMENT BETWEEN JUNE 25 AND JULY 14.

(*Drawn by W. Tempel.*)

bent round towards the tail, which it assisted in providing with a bright exterior edge."

The comet was nearest to the Earth on July 21, when its distance was less than it had been on July 13 by 9,000,000 miles. During this week the comet's tail remained visible, stretching towards the N. for some hours after the nucleus had descended below the horizon. It would have been an exceedingly striking object all this week if it could have been seen as a whole, but it had got too close to the Sun. The tail reached a length of 43° on July 19, but on the evening when Brodie's sketch was made it was no more than 20°. Coggia's Comet undoubtedly revolves in an elliptic orbit, but there is great discordance in the values given of the period. Seyboth's period is 5711 years; but Geelmuyden put it as high as 10,445 years.

The Comet of 1880 (i.), generally called the "Great Southern Comet of 1880", was noticed by several persons in Australia, South America, and South Africa on Feb. 1, but its cometary nature seems not to have been recognised till the following night. Gould at Cordoba described the tail as 40° long and from $1\frac{1}{2}°$ to $2\frac{1}{2}°$ broad, but at no time was the nucleus very bright. The elements closely resemble those of the great Comet of 1843, also celebrated, as we have seen, for the length of its tail, but the identity of the 2 bodies has not yet been satisfactorily established.[o] This comet was unfavourably placed for observation, and was only seen for 2 or 3 weeks.

The Comet of 1882 (iii.) was in some respects one of the most remarkable seen by the present generation of astronomers. It was conspicuously visible to the naked eye for some weeks in September, and altogether remained in sight for the long period of 9 months. The special peculiarities which seem to differentiate this comet from all others which have been exhaustively scrutinised, either before or since, were that the head underwent changes in the nature of disruptions; that the tail may have been tubular; that the extremity of the tail was not only bi-fid (or split), but that it was entirely

[o] For detailed observations see *Month. Not. R. A. S.*, vol. xl, pp. 295, 377, 623, March, April, 1880; *ibid.*, vol. xli, p. 85, Dec. 1880.

unsymmetrical, considered in relation to the greater part of the tail; and that on one occasion the comet seems to have thrown off a mass of matter which became, and for several days was observed as, a distinct comet. The changes which took place in the nucleus and head were noted and described by many observers. Prince wrote:—

"Oct. 13.—I could notice, however, that there was a decided change in the appearance of the nucleus. Instead of being of an oval shape, it had become a long flickering column of light in the direction of the tail."

"Oct. 20.—I noticed, however, at once, that a still further change had occurred in the nucleus since the 13th, which amounted, in fact, to its disruption into at least 3 portions."

Fig. 83.

THE GREAT COMET OF 1882. FORMATION OF THE NUCLEUS. (*C. L. Prince.*)

"Oct. 23.—The disruption of the nucleus which I had noticed on the 20th was now fully apparent. The nucleus proper had become quite linear, having upon it the 4 distinct points of condensation which I have endeavoured to represent in the subjoined sketch.

"It must be understood that the accompanying woodcut is to be considered rather as a *diagram* of the head of the comet than as a view of what I actually observed, and that the *points* in question are somewhat exaggerated in size, as well as the linear character of the nucleus itself. I found it was very difficult to represent, by means of a wood-block, such a nebulous object; but I think it will serve to illustrate the nature of the wonderful disruption, and the relative distance of the several portions *inter se*: *a* was the most difficult portion to discern; *b* was by far the brightest of all; *c* was considerably less bright than *b*; and *d* was nearly as faint an object as *a*, and not quite so large. The linear nucleus, with these points of condensation upon it, was surrounded by a distinct oblong coma, which was rounded off at the lower extremity, while the upper portion, following the direction of the tail, terminated more decidedly in a point. Mr. G. J. Symons, F.R.S., was with me in the observatory, and his impression was that there were *five* points of condensation, and he remarked that 'the nucleus was like

a string of beads'. At intervals I thought there *was* another point of light between *b* and *c*, but as I could not absolutely satisfy myself of its objective existence, I have only represented the four portions, of the presence of which I entertained no doubt whatever. Both Mr. Symons and myself particularly noticed the frequent flickering of the light of the nucleus, which was quite apparent both to the naked eye and in the telescope."

J. F. J. Schmidt published a sketch of the nucleus which is not unlike Prince's; and having seen Prince's he refers to it as a good representation of what he had seen himself. He noticed a vibratory motion in the fan.[p]

The suggestion that the comet's tail was tubular in form is due to Tempel, who brought out the idea in some striking sketches which he sent to the Royal Astronomical Society, accompanied, for the sake of comparison, by a drawing of the appearance of 2 hollow glass cylinders as seen in the focus of an eyepiece.[q]

The peculiar shape of the extremity of the tail will be sufficiently indicated by the accompanying woodcut of a drawing by B. J. Hopkins.[r] [Fig. 84.] His simile was that the general form of the tail resembled the Greek letter γ.

The peculiar shape of the tip of this comet's tail was mentioned by most observers. This feature, though rare as regards the comets of the last half century, may be conceived to be the shape meant by old writers when they speak (as they often do) of having seen a comet resembling in form "a Turkish scymitar".

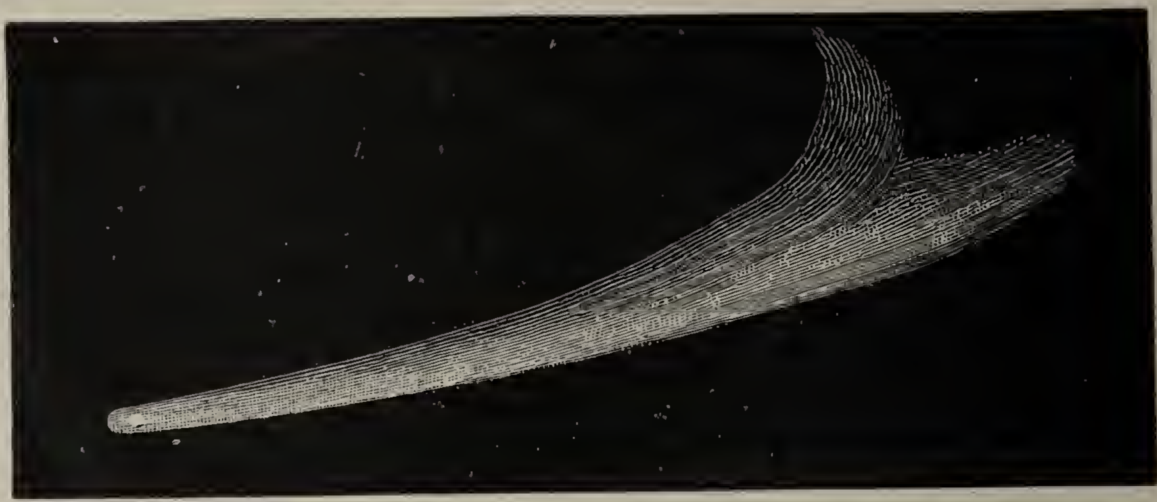
The most noteworthy physical peculiarity of the Comet of 1882 was its throwing off a mass of matter which became a satellite comet, as recorded by Schmidt at Athens, and by Barnard and Brooks in America. Perhaps it is going too far to speak quite as definitely as this, but the fact is clear that Schmidt saw on Oct. 9, and on two or three later days, a nebulous mass in the neighbourhood of the comet which calculation indicated to be cometary matter moving round the Sun in an orbit considerably resembling the orbit of the comet. Brooks's observation made on Oct. 21 was that he saw a nebulous mass on the opposite side of the comet to

[p] *Ast. Nach.*, vol. cv, No. 2499. March 19, 1883.

[q] *Month. Not. R. A. S.*, vol. xliii, p. 322. April, 1883.

[r] *Month. Not. R.A.S.*, vol. xlii, p. 90. Jan. 1883.

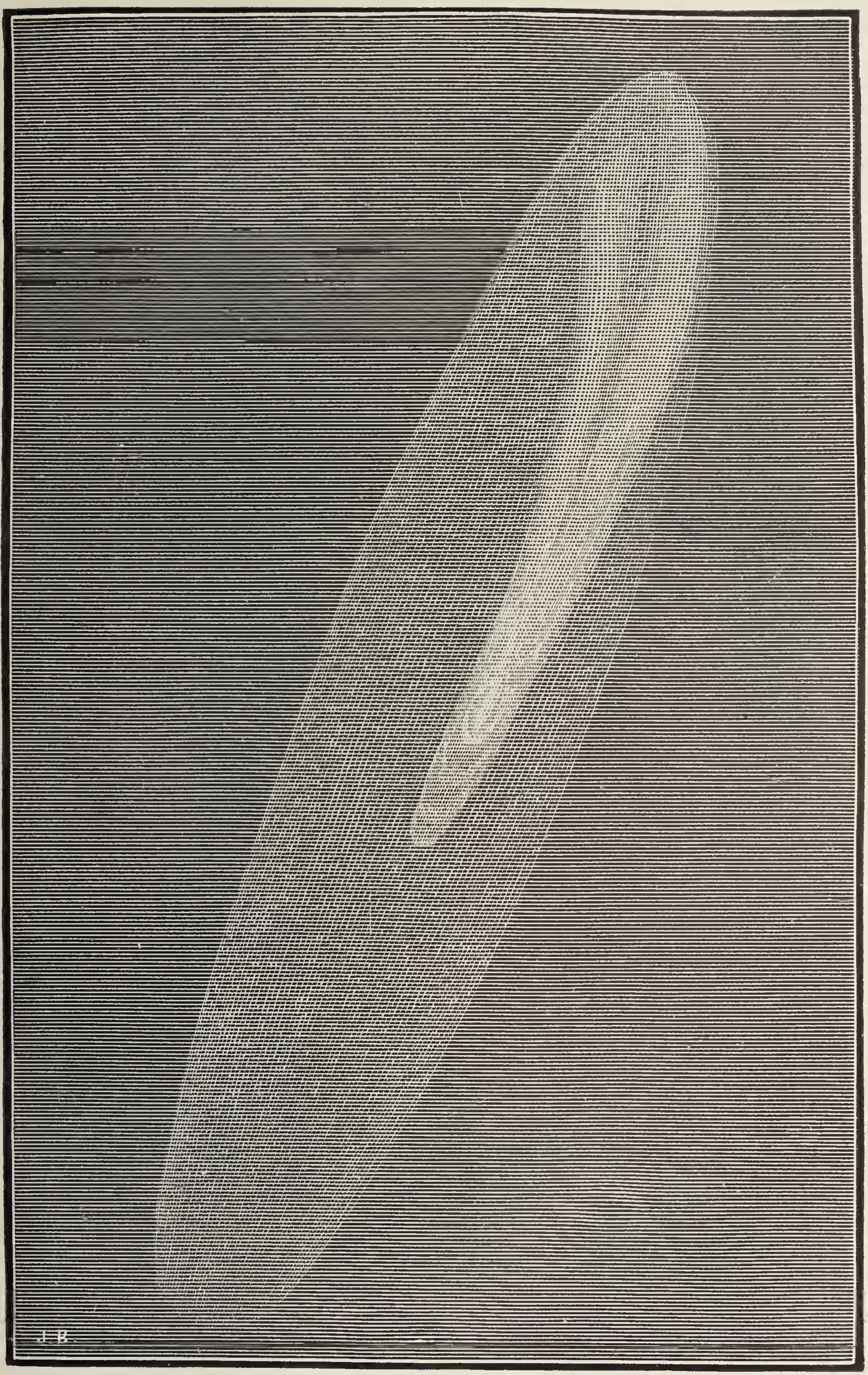
Fig. 84.



THE GREAT COMET OF 1882. NAKED-EYE VIEW ON NOV. 14. (*B. J. Hopkins.*)

Fig. 85.

THE GREAT COMET OF 1882, ON OCT. 9 AT 4^h A.M. (*Flammarion.*)



THE GREAT COMET OF 1882: OCT. 19.
(*Drawn by Gen. G. H. Willis.*)

Schmidt's mass.[s] With the evidence before us of what happened in 1846 in the case of Biela's Comet, it is impossible not to draw the inference that the nebulous mass (or masses) was, or had been, a part of the comet itself; and this theory becomes much strengthened when read in the light of the disruptive changes which the nucleus underwent as already mentioned.

General Willis observed the comet at sea 70 miles E. of Gibraltar on Oct. 19 at 5 a.m. with the air extremely clear and calm. He says that in appearance the comet was so "extremely delicate, light, and airy, that it would be almost impossible to depict it on paper". The engraving [Plate XXIV.] is a French reproduction of the original English lithograph.[t]

Holden contributed some information bearing on the question of disruption. His sketches tell their own tale. With reference to their dates, Oct. 13 and Oct. 17, it may be remarked that two of the nuclei seen by Holden were seen by Cruls at Rio de Janeiro at the intermediate date of Oct. 15. Cruls found these nuclei to resemble stars of the 7th and 8th magnitudes respectively, the distance between them being $6\frac{3}{4}''$. He was led to regard the peculiar appearance of the tail as being really due to two tails, one superposed upon the other, each connected with a nucleus of its own, independent of the other.

Not only did this comet puzzle astronomers very much in the matter of its physical appearance, but its orbit has also been a source of great searchings of heart.[u] The elements closely resemble those of the Comet of 1880 (i.), the "great Southern Comet of 1880" just described. This in turn was considered to be a comet moving in an elliptic orbit with a period of about 37 years, and to be in fact a return of the celebrated Comet of 1843. It still remains a moot point what interpretation is to be put upon these orbital resemblances, the fact of which cannot be questioned. And there is the further complication that since the advent of the Comet of 1882

[s] *Sidereal Messenger*, vol. ii, p. 149. Aug. 1883.

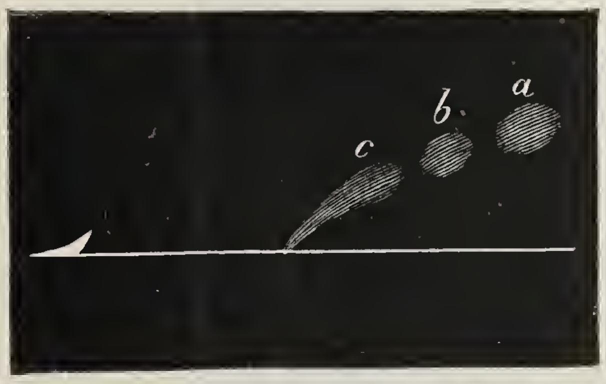
[t] *Month. Not. R.A.S.*, vol. xliv, p. 86. Jan. 1884.

[u] This matter has already been dealt with in some detail (see p. 17, *ante*), but a recapitulation seemed desirable.

another one has presented itself, namely the Comet of 1887 (i.), whose elements also bear a strong resemblance to those of the 3 comets just mentioned. The suggestion has been made that these 4 comets, all of them large ones (and perhaps another also), had a common origin, but that by some process of disintegration the original mass yielded 4 or more fragments which, pursuing paths only slightly different, have arrived at perihelion at different epochs. It will be seen at once that this is a very speculative question.[x]

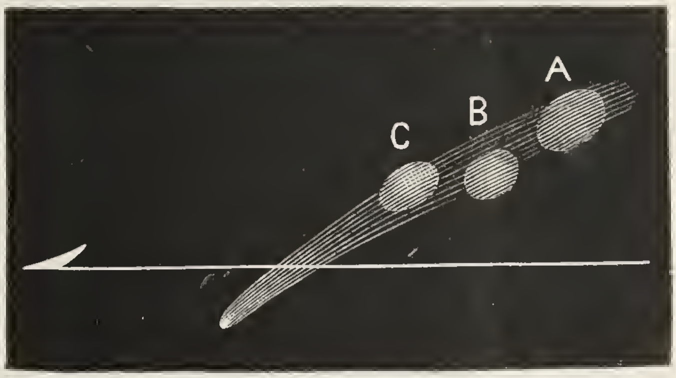
The Comet of 1887 was seen only in the Southern hemi-

Fig. 87.



Oct. 13. (*Holden.*)

Fig. 88.



Oct. 17. (*Holden.*)

THE COMPOUND NUCLEUS OF THE GREAT COMET OF 1882.

sphere. It seems to have been first seen in South Africa by a "farmer and fisherman" at Blauwberg near Cape Town on Jan. 18. Finlay, who first saw it on Jan. 22, describes it as "a pale, narrow ribbon of light, quite straight, and of nearly uniform brightness throughout its length. There was no head or condensation of any kind visible near the end, the light simply fading away to nothing". The tail was described by Todd, at Adelaide, Australia, as a "narrow nebulous streak"; but the remarkable thing is that the tail was as much as 30° or more long, according to several observers. To both Finlay and Todd this comet recalled the great Southern Comet of

[x] *Month. Not.*, vol. xliii, p. 108, Feb. 1883; *ibid.*, vol. xlviii, p. 199, Feb. 1888. For various drawings of the Comet of 1882 see *Ast. Nach.*, vol. civ, No. 2489, Feb. 5, 1883 (Barnard); vol. cvi, No. 2535, Aug. 31, 1883 (Hartwig); vol. cvii, No. 2550, Oct. 31, 1883 (Peters); *Month. Not.*, vol. xliii, p. 288, March, 1883 (Brett).

1880 as regards its appearance, and Finlay was so impressed by the resemblance that he took steps to investigate its orbit, and, strange to say, found that the resemblance even extended to that detail. His conclusion was thus expressed:—"These elements though of course, rough, prove conclusively that the comet belongs to the family of 'Sun-grazers' of which 1843 (i.), 1880 (i.), and 1882 (ii.) are members."[y]

Sawerthal's Comet of 1888 (i.) exhibited on March 27 a triple

Fig. 89.

THE GREAT COMET OF 1901 (ii.) ON MAY 12.
(*Drawn by J. Lunt.*)

nucleus not unlike that of the great Comet of 1882.[z] This comet had a tail which on April 11 was 5° long. It revolves in an elliptic orbit to which a period of 1615 years has been assigned. The configuration of the head was very remarkable and unusual.

The Comet of 1901 (i.), discovered at Paysandu in South America on April 12, but scarcely reached from any obser-

[y] *Month. Not. R. A. S.*, vol. xlvii, p. 303. March 1887.

[z] Letter of M. Cruls in *Ast. Nach.*, vol. cxix, No. 2842. May 26, 1888.

vatory in the Northern hemisphere except the Lick, in California, has some claim to be called "remarkable". Its main tail, which did not exceed 10° in length, was preceded by a faint tail fully 30° long, which branched out from the main tail, making with it an angle of about 40° or nearly half a right angle. On April 24, although in twilight, the nucleus was very bright and distinctly of a yellow tinge, as seen by Innes at the Cape Observatory. On May 12, though the comet had become intrinsically much fainter, it was still

Fig. 90.

BROOKS'S COMET OF 1902 (i.). (*Drawn by W. R. Brooks.*)

a magnificent object, and in between the 2 tails spoken of above 2 other slender tails were visible. The spectrum appeared to be continuous. The comet was visible for about 6 weeks, but bad weather both at the Cape and in Australia and the comet's inconvenient position with respect to the Sun interfered very much to prevent a good series of observations. On May 2 the nucleus is said to have rivalled Sirius in lustre and to have been distinctly elliptical in shape. Eddie, at Naauwpoort in S. Africa, speaks of the matter composing the long tail as being "striated" in appearance.[a]

[a] See *Month. Not. R. A. S.*, vol. lxi, p. 508, June 1901; and *ibid.*, vol. lxii, p. 194, Feb. 1902.

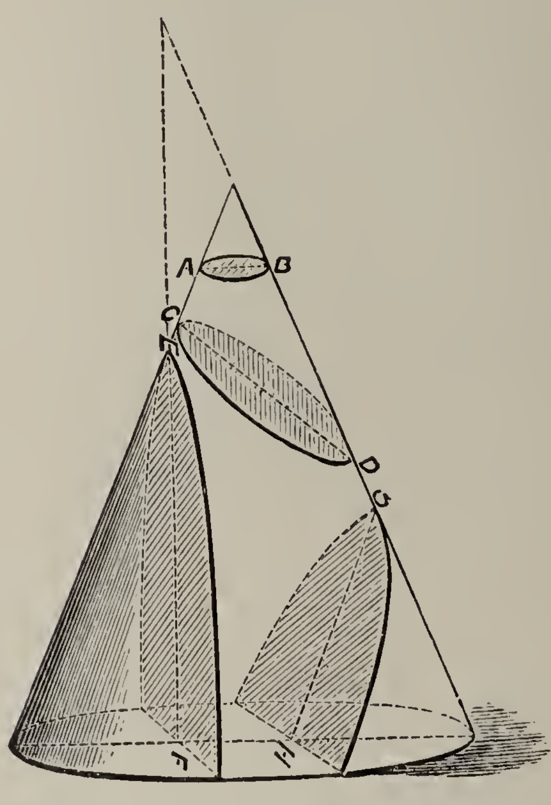
CHAPTER XI.

THE ORBITS OF COMETS.

All Cometary Orbits sections of a Cone.—The different kinds of Sections.—The Circle.—The Ellipse.—The Hyperbola.—The Parabola.—The last-named the most easy to calculate.—An ellipse very troublesome to calculate.—The elements of a Comet's Orbit.—For a Parabolic Orbit 5 *in number.—Statement of various details connected with Orbits.—Direction of motion.—Eccentricity of an Elliptic Orbit.—The various elements represented by certain symbols.—Number of comets whose Orbits have been calculated.—The significance of the different Orbits pursued by comets.*

It has already been stated, but without much explanation, that all comets move in orbits which are either elliptic, parabolic, or hyperbolic—3 of the 4 possible sections of a cone. Fig. 91 represents the various sections of a right cone, as it is called, and will convey a better idea of Cometary Orbits than a verbal description would do. When a right cone is cut at right angles to its axis the resulting section A B, will be a *Circle*: no comet, however, is known to revolve in a circular, or even in anything like a circular orbit, though, on the other hand, all the planetary orbits may be said to be nearly circular. When a cone is cut obliquely, so that the inclination of the cutting plane to the axis of the cone is *greater than* the constant angle formed by the generating line of the cone and the axis, as C D, the resulting section will be an *Ellipse*, the shape of which will vary from almost a circle on the one hand to almost

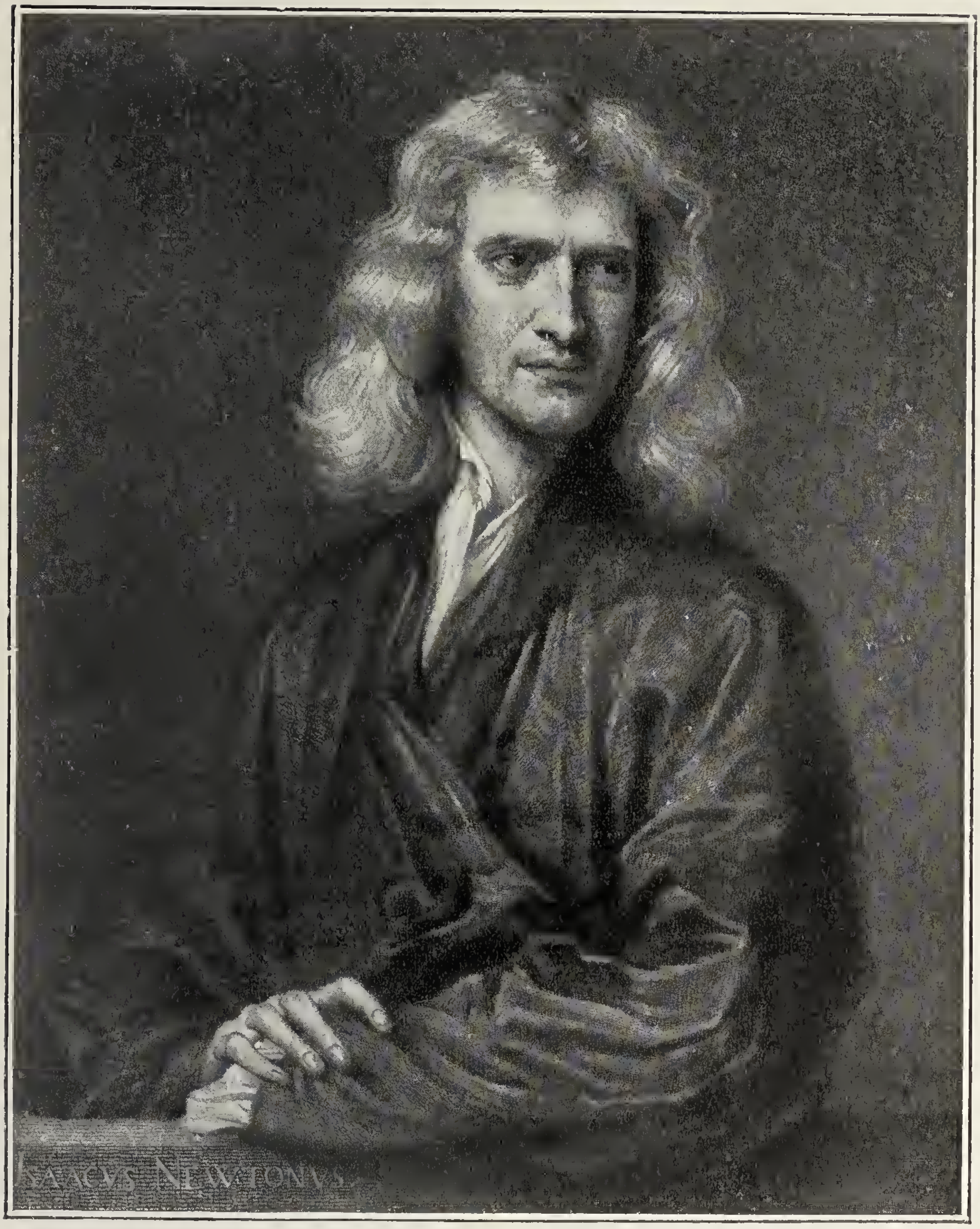
Fig. 91.



THE VARIOUS SECTIONS OF A CONE.

Fig. 92.

Plate XXV.



SIR ISAAC NEWTON.

a parabola on the other, according to the amount of the obliquity. When a cone is cut in a direction so that the inclination of the cutting plane to the axis of the cone is *less than* the constant angle formed by the generating line of the cone and the axis, as E F, the resulting section will be a *Hyperbola.* When a cone is cut in a direction so that the inclination of the cutting plane to the axis of the cone is *equal to* the constant angle formed by the generating

Fig. 93.

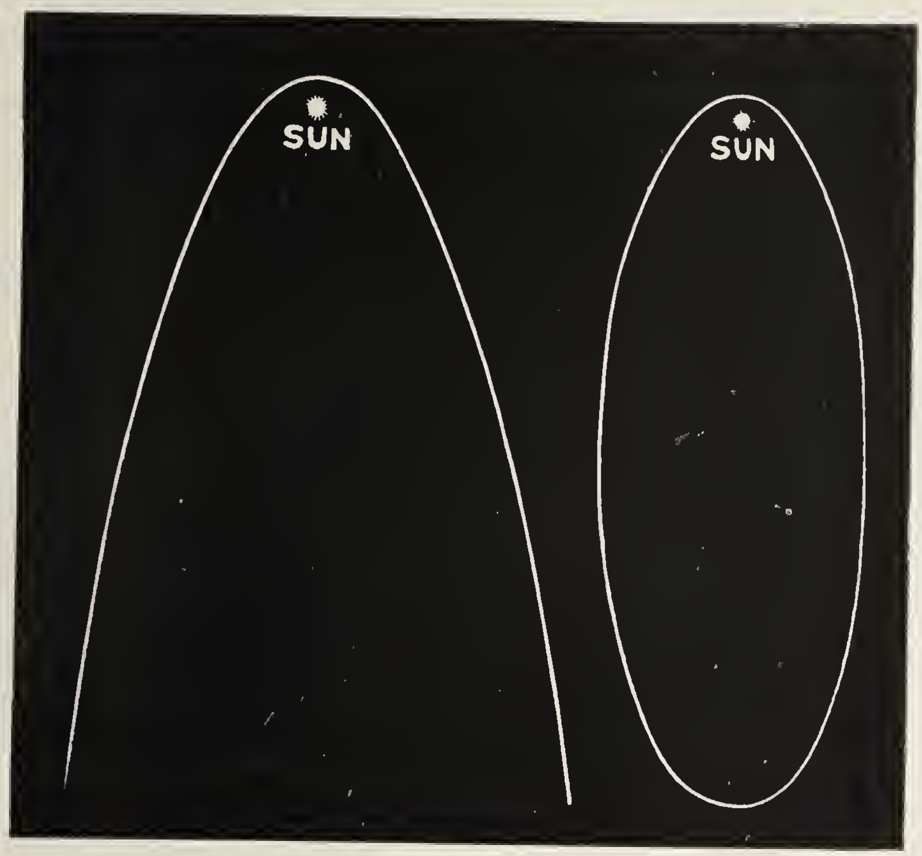


DIAGRAM OF A PARABOLIC AND AN ELLIPTIC ORBIT.

line of the cone and the axis, as G H, the resulting section will be a *Parabola.*

It will be evident from an inspection of the diagram that no comet can be periodical which does not come to us following an elliptic path. In consequence, however, of the comparative facility with which a parabola can be calculated, astronomers are in the habit of seeking to apply that curve to represent the orbit of any newly discovered body. Parabolic elements having been obtained, a search is then made through a catalogue of comets whose orbits have already been calculated, to see whether the new elements resemble

those of any comet which has been previously observed: if so (especially if the parabolic elements indicate a path through the heavens which is evidently not the path being followed by the comet), calculations for an elliptic orbit are undertaken and a period (usually stated in years and decimals of a year) is deduced. To compute an elliptic orbit for a comet or planet will take even an experienced calculator many hours of very hard work. An approximation may, however, be obtained by a graphical process.[a]

It will be desirable to give the reader a little further insight into the nature of cometary orbits without going more deeply than can be helped into mathematical matters.[b] The orbits of all comets, planets, and binary stars are in form sections of cones, whose size, exact form, and position in space are defined by numerical quantities technically termed "elements", which for brevity's sake are usually designated by symbols as follows:—

T = Moment of the body's *Perihelion Passage* or nearest approach to the Sun,[c] expressed in Greenwich, Berlin, or Paris time according to the nationality of the computer, Americans adopting Greenwich time.

λ = *Mean Longitude* at an Epoch given. Instead of this some computers give the "Mean Anomaly at Epoch", and often it is not explicitly stated which is intended. But in neither case is it an independent element, since it is deducible from the time of the Perihelion Passage (T) and the Rate of Motion (μ). In fact, where this element is given (namely, in elliptic orbits), the time

[a] Such as that framed by Mr. F. C. Penrose, which is presented in my *Handbook of Astronomy*, 4th ed., vol. i, p. 491 *et seq.*

[b] Perhaps the best way of realising clearly the nature of a comet's orbit, and the difference between one orbit and another, is by making cardboard models. For instructions how to do this see an article by a distinguished American astronomer, Professor Harkness, in the *Sidereal Messenger*, vol. vi, p. 329. Dec. 1887. I have epitomised some portions of that article in the next following statement of the elements of an orbit.

[c] In the case of a binary star, of the nearest approach of the companion star to the principal star; in such case the point of nearest approach is called the *peri-astron* instead of the *peri-helion*.

of Perihelion Passage is generally *not* given, but left to be inferred from the other.

π = *Longitude of the Perihelion*, or the longitude of the body when it reaches that point. In the case of a comet (or planet), this is measured along the ecliptic from the vernal equinox to the comet's ascending node, and thence along the comet's (or planet's) orbit to its Perihelion; in the case of the Earth, it is measured along the ecliptic from the vernal equinox to the Perihelion. [Crommelin has drawn attention to the fact that some founts of Greek type have the small *Pi* in this shape (ϖ) instead of the common (π). This anomalous *Pi* too nearly resembles the *Omega* (ω) employed in stating the elements of an orbit: hence the risk of confusion.]

☊ = *Longitude of the Ascending Node* of the body's orbit as seen from the Sun (or Primary); measured on the ecliptic from the vernal equinox to the ascending node of the orbit.

i = *Inclination* of the plane of the orbit to the plane of the ecliptic.

e = *Eccentricity* of the orbit, sometimes given as a decimal, and sometimes as an angle, ϕ. The decimal represents the ratio of the linear distance of the centre of the ellipse from the focus, to the semi-axis major, the latter being taken as 1·0. When ϕ is given, then e = the natural sine of ϕ. This is the angle formed by the *minor* axis at its extremity on the border of the ellipse with a line drawn from thence to the focus. The greater this angle the more eccentric the ellipse.

q = Perihelion distance of the body; expressed in terms of the mean radius of the Earth's orbit as unity.

For a parabolic orbit e is always 1·0 (or Unity); and in that case the elements are frequently given by stating T, ω, ☊, i, and log. q. Here π has been replaced by:—

$$\omega = \pi - ☊, \qquad (1)$$

which is counted on the comet's orbit, backward, from the

perihelion to the ascending node; and the perihelion will lie on the northern or southern side of the ecliptic according as ω is less or greater than 180°.

As π and Ω are counted from the vernal equinox, and i is measured from the plane of the ecliptic, the quantities necessarily refer to a particular equinox, and this is always specified.

It was long customary to measure longitudes in the orbits of comets in the direction of the Earth's motion; to limit i to the first quadrant; and to specify the direction of the comet's motion, whether "direct" or "retrograde"; but many astronomers, especially on the Continent, now follow Gauss in regarding retrograde motion as a result of the inclination passing into the second quadrant; and in accordance with that view they measure a comet's longitude always in the direction of its own motion, and permit i to take any value between 0° and 180°. The circumstance that i is measured at the ascending node limits its range to the first and second quadrants, for if it were to pass into the third or fourth quadrants the ascending node would be converted into a descending one. For a comet having direct motion the numerical values of the elements are the same in Gauss's system as in the old system, but for a comet having retrograde motion they are different, and in that case, if their values according to the old system are indicated by a subscript $_0$, the equations requisite for passing from the old to the Gaussian system are:—

$$i = 180° - i_0 \qquad \omega = 360° - \omega_0 = -\omega_0$$

$$\Omega = \Omega_0 \qquad \pi = 2\,\Omega_0 - \pi_0$$

There is frequently much confusion respecting the angles π and ω, and it is important to have a clear understanding of the relations of ω to π and Ω. In the old system of elements π is measured from the vernal equinox, along the ecliptic in the direction of the Earth's motion, to the ascending node of the comet, and thence along the comet's orbit, *still in the direction of the Earth's motion*, to the comet's perihelion. In Gauss's system π is measured from the vernal equinox, along the ecliptic in the direction of the Earth's motion, to the

ascending node of the comet, and thence along the comet's orbit, *in the direction of the comet's motion*, to the comet's perihelion.

These definitions may perhaps be elucidated by the following statement. Imagine a perpendicular to the plane of the ecliptic, erected from the Sun. Then to an observer situated North of the ecliptic in that perpendicular, the motion of the Earth will be contrary to the hands of a clock, and longitudes in the Earth's orbit will increase in that direction. Now consider a comet's orbit; imagine a perpendicular affixed to it in such a way that when the inclination of the orbit to the plane of the ecliptic is i, the inclination of the perpendicular shall be $(i+90°)$; and suppose an observer so situated in the perpendicular that when $i=0°$ he shall be North of the ecliptic. Then, according to the old system of elements, for all possible values of i the observer will remain North of the ecliptic, and the motion of the comet will appear to him as *contrary* to the hands of a clock when Direct, and *with* the hands of a clock when Retrograde; but according to Gauss's system he will be North of the ecliptic when i is less than 90°, South of it when i is greater than 90°, and to him the apparent direction of the comet's motion will always be *contrary* to the hands of a clock.

Whichever system is adopted, from this point of view π will always increase contrary to the clock, and to find the intersection of the plane of the comet's orbit with the plane of the ecliptic, or, in other words, the line of the nodes, the observer must set off ω in the direction of the hands of a clock, from the perihelion of the orbit.

Cometary orbits cross the ecliptic at all sorts of angles between 0° and 90°. A small inclination (say, under 15°) may often be interpreted as a sign of periodicity,[d] because all the short-period comets have small inclinations. By moving so near the ecliptic their chances of being "captured" by planets is great. On the other hand, a comet with a large inclination (say 70° to 90°) runs small risk of being "captured", because

[d] Because all the planets which are periodical bodies (so to speak) have small inclinations; except a few minor planets.

its stay near the region of planets lying in wait, as it were, for comets is limited in time. It runs down to the ecliptic: is quickly across, and off again on the other side, and is soon out of reach of a planet prowling along the ecliptic to see what it can catch.

The motion of a comet is said to be "Direct" (represented by +) when it moves in the order of the signs of the Zodiac, and "Retrograde" (represented by −) when it moves contrary to the signs of the Zodiac.

In the case of an elliptic orbit, given q and e we can ascertain the length of the major axis (a).

Given the daily motion (μ) we can obtain the period in days by dividing 1,296,000 (the number of seconds in a circle of 360 degrees) by the value of μ.

Astronomers are in the habit of performing all these calculations by logarithms because of the ease and convenience of doing so.

Be it remembered that the "eccentricity" is not the linear distance of the centre of the ellipse from either focus, but the ratio of that quantity to the semi-axis major.

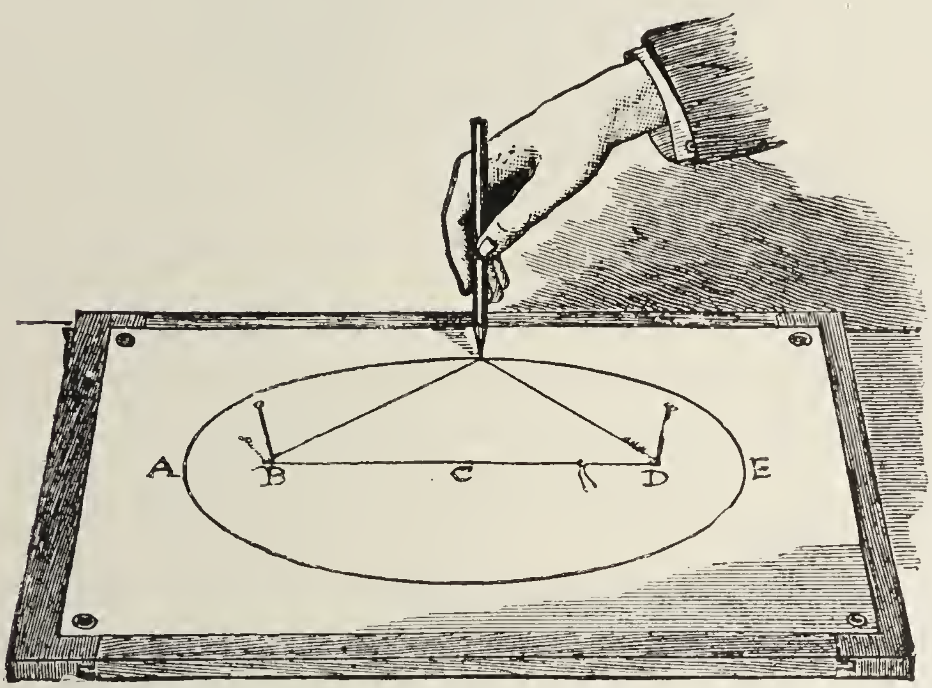
Fig. 94 represents the usual way of drawing an ellipse on paper. A line joining AE would be the "axis" of the ellipse, a line at right angles to this at A would be the "directrix" of the ellipse. B and D are the foci; and taking B to be the principal focus, B would be the place of the Sun, supposing the ellipse to represent the path of a comet revolving in an elliptical orbit. AC would be the "semi-axis major" or "mean distance"; and the eccentricity would be the ratio of BC to AC, which in this particular diagram would be about 7 to 10, or decimally 0·7. The diagram therefore represents nearly the shape of the orbit of Winnecke's comet.

Up to the present time the orbits of nearly 400 *different* comets have been calculated. This does not include orbits of comets which have returned one or more times after their first discovery and recognition as being periodical comets.[e]

[e] Gauss's *Theoria Motus Corporum Cœlestium*, 4to, Hamburg, 1809, was long reckoned the standard work on the subject of orbits, but it has in some degree been superseded by Oppolzer's *Lehrbuch zur Bahnbestimmung*

When a new comet has been discovered and its elements have been ascertained, it is usual for some astronomer, specially interested in the particular comet, to provide a table of predicted places for the comet many days or weeks in advance. Such a table is called an "ephemeris", and will enable other astronomers to know where to look for the new body, and, finding it, to obtain observations

Fig. 94.



THE CONSTRUCTION OF AN ELLIPSE.

which will be available for improving the accuracy of the elements first circulated.[f]

The significance of the various sections of a cone which constitute the different forms of orbit affected by comets is well and tersely stated by Howe[g] in the following extract:—"Suppose that a small body is at a very great distance from the Sun, and both bodies are motionless. The body will begin to fall toward the Sun, its path being

der Kometen und Planeten, 2nd ed., 2 vols. 8vo, Leipzig, 1882. A French translation by a Belgian, M. E. Pasquier, was published at Paris, 1886, under the title of *Traité de la détermination des orbites des comètes et des planètes.* See also a paper by Airy, in *Memoirs R.A.S.*, vol. xi, p. 181. 1840.

[f] Instructions how to compute an ephemeris for a comet after the elements have been ascertained will be found in *Popular Astronomy*, vol. ix, p. 311. June and July 1901.

[g] H. A. Howe, *Elements of Descriptive Astronomy*, New York, 1897, p. 189.

a straight line directed towards the Sun's centre. Another small body, likewise at a distance practically infinite, has a slight motion of its own, but is not moving *directly toward* the Sun; urged on by the Sun's imperious attraction, its velocity will continually increase; however, as it is not going directly toward the Sun, it will not strike it, but as it goes past, the pull of the Sun will cause its path to be violently curved; whirling around the Sun, it will return toward the infinite depths of space from which it came, its orbit becoming a *parabola.* A body which has originally a very considerable velocity of its own will come down to the sun in an hyperbolic orbit, and then retreat, never again to visit us. A body moving in a parabola may have its velocity checked, as it approaches the Sun, by the attraction of some planet; its orbit will thus be changed to an *ellipse.* Were the movement of the body accelerated by the planet's action, the orbit would become an *hyperbola.*"

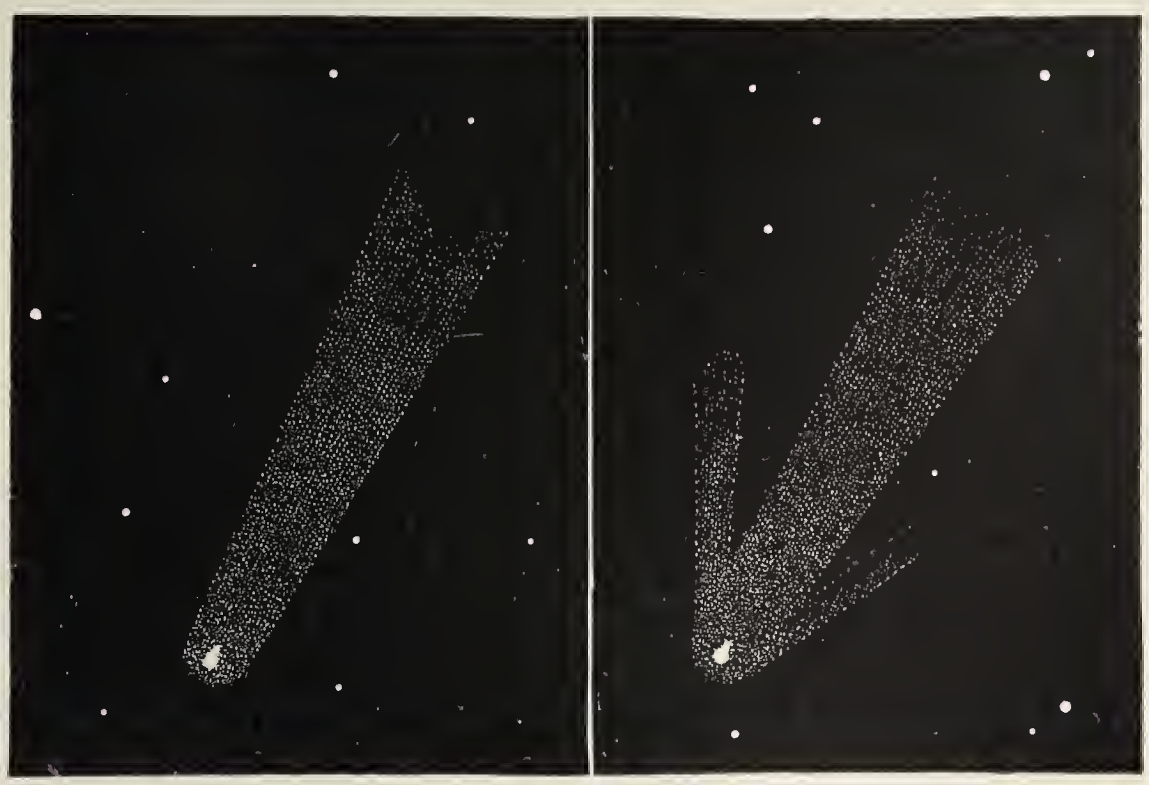
Scarcely less interesting than the question "What is a comet?" are the cognate questions "Why do comets come to us?" and "Where do they come from?" It is obvious that these questions can only be answered in a hypothetical and inadequate fashion, but still it is possible to say something. Two provisional answers suggest themselves: either (1) comets are chance visitors wandering through space and now and again casually caught up by the Sun, or by some of the major planets acting like the old naval press-gang and compelling them to attach themselves to the Sun and by taking elliptic orbits to become permanent members of the solar system; or (2) they are aggregations of primæval matter not formed by the Creator into substantial planets, but left lying about in space to be picked up and gathered into entities as circumstances permit.

C. L. Poor has graphically summarised the situation. At the risk of a little repetition, I will transcribe what he says:—"They have been considered as true wanderers, travelling through space, drifting hither and thither, just as the Sun, with its attendant retinue of planets, is moving onward in some unknown path. When the paths of the Sun and such

Fig. 95.

DISCOVERY FIELD OF BROOKS'S COMET OF 1890 (ii.) ON MARCH 19.
(*Drawn by W. R. Brooks.*)

Fig. 96.



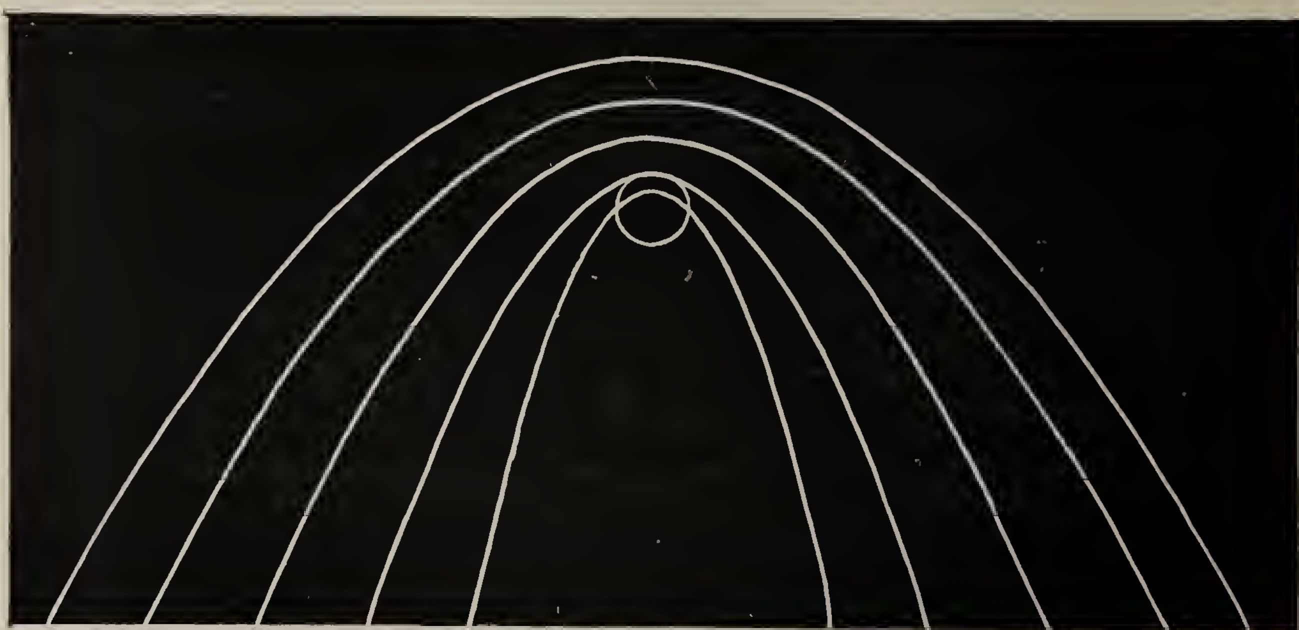
July 23. July 26.

THE BROOKS-BORELLY COMET OF 1900 (ii.).
(*Drawn by W. R. Brooks.*)

a free comet approach, the attraction of the Sun is to the comet like the flame to the moth; the comet flutters for a moment about the Sun, and passes on its way. But not unscathed; like the moth, the comet has been singed; the fierce light of the Sun has beaten upon it, and spread out its particles and scattered them along its path.

"This idea that comets originate outside the solar system rests upon the supposed character of their orbits. The great majority of these strange bodies appear to travel in parabolas, open curves leading from infinite space to and around the Sun

Fig. 97.



(*W. B. Gibbs, del.*)

FIVE PARABOLAS
at $\frac{1}{2}$, 1, 2, 3, AND 4 RADII OF THE EARTH'S ORBIT.

and thence back into the region of the fixed stars. Sir Isaac Newton first showed the possibility of comets moving in such paths, and the prestige of his name and the ease and facility with which parabolic orbits can be calculated led to the adoption of this curve as representing the motions of these bodies. Under the Law of Gravitation a body may travel about the Sun in any one of the three conic sections, or curves, known as the ellipse, the parabola, and the hyperbola. That is, if there were in the universe but two bodies, the Sun and a comet, then would the comet describe about the Sun one of these three mathematical curves, the exact character and size of the curve depending solely upon the speed of the

comet relative to the Sun at the beginning of time. But the instant a third body is added to the system this is no longer true. The parabola is a limiting curve, is what might be called a curve of 'unstable' motion. To describe a parabola about the Sun, a body must have at each point of its path a certain definite velocity. If this parabolic velocity be changed by the slightest amount, the path ceases at once to be a parabola; if through any cause the velocity be decreased the path becomes an ellipse; if increased, an hyperbola. Now if a comet start in a parabolic orbit, it cannot continue for a single instant in that path, for it must of necessity be attracted by Jupiter, by Saturn, or by some or all of the planets, and such attraction will either increase or decrease its speed. Thus a parabolic orbit is a physical impossibility.[h]

"Yet to-day the greater number of newly discovered comets are classed as parabolic, and their orbits are computed and given as parabolas. This is because a very small part of the actual orbit is seen, such a small part that it is impossible to determine the exact character of the real path. Near perihelion the difference between an elliptic orbit of great eccentricity and a parabolic orbit is so slight as to be inappreciable.[i] On the other hand, the labour of keeping track of a body moving in a very eccentric elliptic orbit is many, many times greater than that required to keep track of a body moving in the corresponding parabola. Parabolic orbits are thus computer's fictions, approximate paths assumed for the purpose of lessening labour."[k]

An exemplification of some of the uses of logarithms in connection with the orbits of elliptic comets may here be given, because some computers in publishing the results of

[h] Though I quote this part of Poor's statement, his way of putting the matter is dissented from by Crommelin, in so far that the assured existence of *any* hyperbolic comets is by no means very clearly assured. Crommelin's words in a letter to me are: "The fact that hyperbolic comets are almost unknown (those that are found are almost parabolic) really shows that all comets belong to the Solar System, for if they came from without, quite a large number would have strongly hyperbolic orbits, owing to the rapid motion of the Solar System through Space."

[i] See Fig. 29 (*ante*, p. 53).

[k] *The Solar System*, p. 281.

their calculations do not always give the perihelion distance of a comet or its periodic time of revolution round the Sun; but limit themselves to announcing the angle of the eccentricity (ϕ), the mean daily motion (μ), and the *logarithm* of the semi-axis major or mean distance (a); leaving the student to find out for himself the perihelion distance (q) and the period.

EXAMPLE.

Given, in the case of Holmes's Comet in 1906—

The angle of eccentricity (ϕ)	24° 20′ 26″
Log. semi-axis major (a)	0·557427
Mean daily motion (μ)	517″·44

TO FIND THE PERIHELION DISTANCE (q).

(i.) Look out in a Book of Tables the Natural Sine of 24° 20′ 26″.

(ii.) Subtract this from Unity (1·0).

(iii.) Find the logarithm of the result.

(iv.) Add this to the logarithm of a.

(v.) And this will give the logarithm of q.

EXAMPLE.

(i a.) Nat. Sine of 24° 20′ 26″ = 0·4121594.

(ii a.) 1·0 − 0·4121594 = 0·5878406.

(iii a.) Logarithm of 0·5878406 is 9·7692595.

(iv a.)

$$\begin{array}{lrl} \text{Add Log. } a & = & 0{\cdot}557427 \\ \text{Log. } (1-e) & = & 9{\cdot}769260 \\ \hline \text{Log. } (q) & & 0{\cdot}326687 \end{array}$$

$\therefore q = 2{\cdot}1217.$

TO FIND THE PERIODIC TIME IN YEARS.

(i.) Calculate number of seconds of arc in 360°.

(ii.) Find logarithm of that number of seconds.

(iii.) Find logarithm of number of seconds travelled over by comet in 1 day.

(iv.) Divide the number of seconds in 360° by number of seconds travelled over by comet in 1 day by subtracting the logarithm of the latter from the logarithm of the former.

(v.) Quotient will be comet's period in days.

EXAMPLE.

(i a.) 1296000″.

(ii a.) Logarithm of this number = 6·1126050.

(iii a.) Mean daily motion being 517″·44, logarithm of mean daily motion = 2·7138600.

(iv a.) Subtract one of these logarithms from the other—

$$\begin{array}{rr} & 6{\cdot}1126050 \\ & \underline{2{\cdot}7138600} \\ \text{Log. Period in days} = & 3{\cdot}3987450 \end{array}$$

$\therefore$ Period = 2504·7 days.
= 6·8 years.

CHAPTER XII.[a]

COMETS IN THE SPECTROSCOPE.

The application of the Spectroscope to Comets.—Photography as applied to the Spectra of Comets.—Historical Survey of the progress made.—Four varieties of carbon Spectra.—Three Comets which have yielded special results.—Conclusions of Hasselberg.—The great Comets of 1881 *and* 1882.—*Schäberle's Comet.—Wells's Comet.—Instruments of a special kind needed for the Spectra of Comets.—Frost's Dictum.—Borelly's Comet of* 1890 (i.).—*Brooks's Comet of* 1890 (ii.).—*Swift's Comet of* 1892 (i.) : *Holmes's Comet of* 1892 (iii.).—*Rordame's Comet of* 1893 (ii.).—*Perrine-Griggs's Comet of* 1902 (ii.).—*Brooks's Comet of* 1904 (i.).—*Daniel's Comet of* 1907 (iv.).—*Morehouse's Comet of* 1908 (iii.).—*One of the most remarkable on record.—Summary of the present state of our knowledge.—Importance of Photography in the study of Comets.—Newall's Theory as to cometary radiation.*

The spectroscope has not been employed in the study of comets on the same scale as it has been used for the purposes of solar and stellar research, and consequently the harvest of knowledge obtained by it has not been so great as one could have wished. Until quite recently most cometary spectra observations were made visually, thus excluding the violet and ultra-violet radiations. Prior to 1902 all attempts to photograph the spectra had been made with long-focus telescopes and spectroscopes, primarily designed for stellar work, a procedure now very generally recognised as inadequate except in the case of an exceptionally bright comet.

A comet is a diffuse object, and is not, usually, very bright. To obtain a spectrum of such an object it is essential that the light be condensed as much as possible; therefore long-focus telescopes and spectroscopes which spread out the light are unsuitable for cometary work. For this reason short-focus prismatic cameras have recently been employed, and

[a] This Chapter is the joint work of Mr. E. W. Maunder and Mr. W. E. Rolston, two experts in spectroscopic work.

the first-fruits obtained give promise of a much richer harvest to follow.

In the case of perhaps no class of heavenly bodies has the spectroscope yielded information of so entirely an unexpected nature as in that of comets. The first comet observed spectroscopically was the Comet of 1864 (i.) by Donati, who found it to yield only 3 bright lines, showing the presence of a glowing gas. Huggins and Secchi, in 1866, found Tempel's Comet likewise gave 3 bright lines and a continuous spectrum in addition. No dark lines were perceived in the latter, the light being probably too faint. But in the continuous spectrum yielded by Coggia's Comet of 1874 some dark lines were seen, and therefore it is reasonable to conclude that the continuous spectrum when given by comets is due to reflected sunlight.[b]

It was an important advance thus to learn that the light of the comet came from two sources; the one from the Sun, by reflection; the other from the comet itself. But the spectroscope speedily revealed a further and unsuspected fact: that intrinsic cometary light was due to glowing hydro-carbon vapour. For Huggins[c] and Secchi in examining the head of Winnecke's Comet in 1868 saw 3 shaded bands, besides the continuous spectrum, and on comparing them with the spectrum of olefiant gas, found that they were exactly coincident with the 3 principal bands of the so-called hydro-carbon spectrum, agreeing with them not merely in position, but in general appearance and in the manner in which they faded away. Coggia's Comet yielded the same result. Since then various comets have been subjected to spectroscopic scrutiny with results which are, on the whole, in remarkable accordance. Three comets, however, stand out from the rest,—Brorsen's Comet as observed by Huggins in 1868; Comet iii. of 1877 as observed by Copeland at Dun Echt; and Holmes's Comet as observed by Keeler in 1892. Excluding these, all the others have shown 3 bright bands coincident with one or other of the carbon spectra.

[b] *Month. Not. R. A. S.*, vol. xxxiv, p. 491. 1874.

[c] *Phil. Trans.*, vol. clviii, p. 555. 1868.

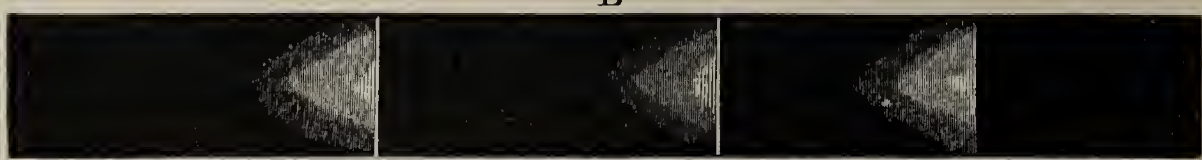
Although mention is made in the previous paragraph of a spectrum there called the "Hydro-carbon" spectrum, its real origin is still unsettled. There are four carbon spectra: (1) a simple line spectrum undoubtedly due to carbon itself; (2) a band spectrum given by the base of a candle flame and often called the "Swan" spectrum after the name of its discoverer; (3) a spectrum usually known as the carbonic oxide spectrum, which also is banded; and (4) a banded spectrum due to cyanogen.

Much discussion has raged around the second, the so-called hydro-carbon spectrum, and its real origin is still so uncertain that Frost, in a recent discussion of Morehouse's

Fig. 98.

A

B



SPECTRA OF OLEFIANT GAS AND WINNECKE'S COMET, 1868.
A, Spectrum of Olefiant Gas; B, Spectrum of Comet.

Comet, refuses to go further than to call it a "carbon" spectrum. Smithells has apparently shown it to belong to carbonic oxide, but the question is too involved for discussion here.[d]

The question however arises, with which of the carbon spectra do the cometary spectra coincide? With regard to the brighter comets the testimony is clear; the spectrum yielded has been that given by the blue base of a candle-flame, or by a Bunsen burner—the spectrum which Lockyer terms that of *hot* carbon, but which Hasselberg and others consider as characteristic of a hydro-carbon, probably of acetylene. The

[d] *Phil. Mag*, 6th series, vol. i, p. 476. April 1901. For further information the reader may consult Baly's *Spectroscopy*, 1905 edition, p. 444.

wave-lengths of the edges of the three principal bands of this spectrum are given by Kayser and Runge as 5635 for the band in the yellow, 5165 for that in the green, and 4737 for that in the blue respectively. But the complete spectrum contains 5 bands, one in the red at 6188 and one in the violet at 4311. These have not often been detected in the spectra of comets, but in the case of one or two of the brightest (the first instance being that of Coggia's Comet in 1874 when Secchi recognised their presence) they have been made out. It appears, therefore, that it is only a question of brightness, and that the whole series may be expected to be shown by any comet of sufficient brilliancy.

In the case of some of the earlier and fainter comets the bright bands were recorded by some observers as coincident with that spectrum of carbon called by Lockyer that of *cool* carbon, by others that of carbonic oxide, in distinction to the hydro-carbon spectrum referred to above. The wave-lengths of the bands in this spectrum are as follows:—yellow, 5609; green, 5198; blue, 4834. It is not yet absolutely certain whether these observations are to be accepted. It appears probable in some cases, if not in all, that the faintness of the spectrum prevented any accurate measurement of the cometary bands, and that being compared with the carbonic oxide spectrum with only low dispersion, and a close approximation being noted, it was assumed that the correspondence was exact. Thus Christie observing the spectrum of Hartwig's Comet on Oct. 7, 1880,[e] measured the green band as at wave-length 5201, or as being the band of the carbonic oxide spectrum: four days later he measured the same band as at 5169, or as being the band of the hydro-carbon spectrum; and on Oct. 12 the observation was repeated. A comparison of the individual measures renders it all but certain that there was no change in the place of the cometary band, and that the difference in the positions recorded was due entirely to the difficulty of securing an accurate measurement of an object so faint and diffused.

[e] *Greenwich Spectroscopic Obs.*, 1880, p. 62.

Hasselberg reviewing the observations of the first 18 comets subjected to prismatic analysis concluded [f] :—

(1) That all observed cometary spectra belong to one type, with the exception of the two doubtful cases of Comets i. 1868, and iii. 1877, noted above.

(2) That this type is that of the hydro-carbons.

(3) That they deviate from the type in being incomplete; and, in general, in the relative brightness of the bands.

(4) That they are incomplete in so far as the red and violet bands of the hydro-carbons are wanting, and also that the maximum brightness of the bands is not at the less refrangible edge, but somewhat towards the violet.

(5) That this circumstance explains why in the case of faint comets the connection with hydro-carbon spectra has appeared doubtful.

(6) That the displacement of the maxima of the bands of most comets, with regard to those of hydro-carbons, is approximately the same; therefore it seems probable that the differences of the physical conditions of the hydro-carbons in the comets, from those which have hitherto been obtained in observations of hydro-carbon spectra, are approximately the same.

The observation of the red and violet bands in Coggia's Comet and in several recent bright comets meets the allegation of incompleteness made above in (4); whilst the shift of the maximum brightness from the edge of the cometary band towards the violet admits often of a very simple explanation. To observe a faint comet the slit of the spectroscope must be opened wide, and probably the light from the whole of the head or from a considerable portion of it will be embraced within the opening. This will not be of one homogeneous brightness throughout, but will fade outwards from the centre; there will be more light near the centre of the slit opening than close to either jaw, and consequently the cometary bands will not only degrade towards the violet, but to a slight extent towards the red as well, throwing the maximum brightness

[f] *Mém. Ac. Imp. de St. Petersbourg*, series vii, vol. xxviii, No. 2; *Copernicus*, vol. i, p. 83.

towards the violet. Thus Konkoly found, when examining Sawerthal's Comet (1888 i.), that the lines were not sharply defined on either side. Consequently his measures of the middle of the maximum light-intensity of the hydro-carbon bands did not coincide with the laboratory wave-lengths. In bright comets when a very narrow slit can be used, and when therefore the entire breadth of the slit is filled with light of practically the same intensity, this discrepancy between the spectra of the comet and of the hydro-carbon disappears. Maunder writes thus in regard to Tebbutt's Comet of 1881:—

> "With the spectra of the Comet and of the Bunsen-flame arranged one above the other, and the flame adjusted until the bright sharp edge of the green band was of the same intensity in each, the resemblance between the two spectra was exceedingly striking, the three principal bands corresponding exactly in position, in brightness, and in the manner and degree in which they shaded off towards the violet."

If this be the correct explanation, there will be no reason to suppose, as in paragraph (6), that the displacement arises from any peculiarity in the physical condition of comets. The displacement will be apparent only, and due to the difficulties of observation.

Beside these shaded hydro-carbon bands, comets generally give a continuous spectrum from the nucleus and the immediate neighbourhood. This is largely due to reflected sunlight, the Fraunhofer lines having been detected on favourable occasions.

The years 1881 and 1882 were especially remarkable for the fine comets which were then visible. Comet iii. of 1881, discovered by Tebbutt, proved especially interesting as the first which was itself successfully photographed, and the first of which the spectrum was photographed, the former feat being accomplished by Janssen, the latter by Huggins and by H. Draper. As first seen in Northern latitudes, the spectrum of Tebbutt's Comet was almost purely a continuous one; it was some few days before the cometary bands began to show themselves. But as the nucleus faded they became more apparent, and their precise coincidence with the bands from a Bunsen-flame was rendered evident. The continuous

spectrum on June 29 showed the Fraunhofer lines, F being unmistakeably present. But the photographic plate had anticipated the eye of the observer, Huggins's negative taken on June 24 showing in the ultra-violet region both the hydro-carbon bands and the solar absorption lines, and proving that the spectrum in the visible portion and in that beyond the grasp of the eye were essentially the same.

The spectrum of the tail of this comet was also examined, and both Vogel and Young traced the carbon bands far down its length, the former indeed to its very end. Probably the spectrum of reflected sunlight was also present, though Young could not trace it so far as he could the gaseous flutings.

Comet iv. of 1881 (Schäberle's) formed a striking contrast to Tebbutt's, in that it gave almost a pure spectrum of bands. The hydro-carbons were strongly in evidence; of reflected sunlight there was scarcely a trace.

Both these comets afforded to Copeland and Lohse a further proof of the origin of their banded spectra, for these observers were able not merely to see simple shaded bands, but to break them up into true flutings precisely as the hydro-carbon spectrum can be resolved.

The Comets of 1882 were yet more important. All the comets which had been previously examined had considerable perihelion distances; Comets i. and ii. of 1882 both approached very near the Sun, the latter all but grazing its surface. The former, known from its discoverer as Wells's Comet, at first showed an almost purely continuous spectrum. The nucleus was greatly condensed, and to direct eye observation and as seen through the prism, it presented a very stellar appearance. On May 27 Copeland suspected the presence of a bright line; the next night the line was seen to be coincident with the D line, and as the result of what he saw on May 29 Copeland wrote [g] :—

"The spectrum of the nucleus of Wells's Comet deserves the closest attention, as it shows a sharp bright line coincident with D, as well as strong traces of other bright lines, resembling in appearance those seen in the spectra of γ Cassiopeiae and allied stars."

[g] *Copernicus*, vol. ii, p. 229. 1882.

Copeland and Lohse followed the comet day by day till its perihelion passage on June 10, and had the gratification of seeing the bright sodium lines, D, develope in the most striking manner. On June 6, the D lines were seen beautifully double, and the continuous spectrum was so much the less important, the light of the comet was so nearly monochromatic, that with a wide slit Lohse was able to see "the perfect image of the comet, head and tail, . . . in the light of the D line, very bright and clear. . . . The sight was really magnificent; exactly like a prominence".

Other bright lines were observed, especially in the red, and there were faint traces of the ordinary carbon bands. But the sodium light was predominant, and, next to that, the general continuous spectrum.

The Great Comet of 1882 approached the Sun much nearer than Wells's Comet had done; and inferring that the development of sodium light in the spectrum of that body had been due to the heat it experienced as it approached the Sun, Copeland and Lohse naturally expected to find the D lines bright also in the spectrum of this new visitor. The inference was justified. "The expected bright sodium lines exhibited themselves to the eye of the observer with a brilliancy and neatness quite comparable to the C line in prominences, so well defined and clear did they stand out on the bright daylight spectrum." But besides the D lines a number of other bright lines were seen, notably the E lines and some other prominent iron lines, together with 5 lines in the red which had no counterparts in the dark lines of the solar spectrum.

A beautiful illustration was afforded by this comet of the effect of the motion of a body on the lines of its spectrum. The comet was receding from the Earth at this time, and the lines of its spectrum were therefore displaced a little towards the red, the bright D and E lines being seen therefore just on the redward side of their dark counterparts in the solar spectrum. This observation was not only made by Copeland and Lohse, at Dun Echt, but on the same day, Sept. 18, by Thollon and Gouy at Nice; and in both cases the displace-

ment was estimated to be about $\frac{1}{4}$ or $\frac{1}{5}$ the distance between the D lines, a displacement which would correspond to a motion of about 42 miles per second. The actual motion of recession of the comet had been otherwise put at about 45 miles per second.[h]

As the comet receded from the Sun the various bright lines faded away, the D lines lasting longer than the others, whilst the carbon bands came into greater prominence. There is every reason to believe that these changes are strictly typical; and that we may expect comets of short perihelion distance to show, first, the hydro-carbon spectrum; then, when in the neighbourhood of the Sun, the sodium lines; and lastly, when at closest approach, a number of other metallic lines, and particularly those of iron. Lockyer carries this view of the successive changes of cometary spectra much further, and has drawn up a long list of the successive phases presented by the spectrum of a comet as the body approaches or recedes from the Sun.[i]

Since 1882 there has been no "great" comet, but improvements in the methods of observation and an increased interest in the physical conditions of these mysterious objects are factors in the case which have more than counterbalanced the lack of bright comets available for investigation. The increased sensitiveness and reliability of the photographic plates in use have also played an important part in the investigations by bringing to light the ultra-violet radiations in which cometary spectra are so rich and to which the eye is blind.

It has already been remarked that the earlier photographic investigations of cometary spectra were made with instruments designed for stellar researches only and unfitted for cometary work. Thus Professor Frost records[k] that, on Oct. 30, 1908, an exposure of 158 minutes with the 40-inch Yerkes refractor and the one-prism Bruce spectrograph failed to give

[h] *Comptes Rendus*, vol. xcv, p. 555, Sept. 25, 1882; and p. 712, Oct. 23, 1882.

[i] *Proc. Roy. Soc.*, vol. xlv, p. 190. Jan. 10, 1889.

[k] *Astrophysical Journal*, vol. xxix, p. 56. January 1909.

any trace of an impression due to the comet, whereas an objective-prism spectrograph, in which the ratio of focal length to aperture was only 6 to 1, gave a good spectrum in 30 minutes. Frost's dictum is that "the great refractor, with its long focal length, is obviously unsuited for such an object".

It is obvious then, that if our knowledge of cometary spectra is to be substantially increased by the appearance of Halley's Comet, or by any other bright comet that may be discovered, the number of these short-focus prismatic cameras and specially designed spectroscopes must be multiplied. By using them while the comets are faint, and then working them in conjunction with the larger instruments—giving more precise results—as the comets become brighter we may be able to throw more light on any spectral changes which take place as the comets approach their perihelia. It is probably behind these spectral changes that the truth lies. That all cometary spectra, at all times, are not exactly alike may now be accepted as proven; and it must be borne in mind that it is from the variations between one comet and another, or in the spectra of the same comet at various times, that we are likely to learn most.

After this digression we will proceed to review the work done during the interval since 1882, which has been an interval marked by a large number of small comets.

Borelly's Comet of 1890 (i.) showed on Jan. 15, according to Backhouse, the three characteristic bands with a faint continuous spectrum, the latter being so faint four days later, on January 19, that its presence was only suspected.

Fowler compared the spectrum of Comet 1890 (ii.) (Brooks's) with the spectrum of the blue base of a spirit-lamp flame, and found [l] that the bands coincided, with the exception of the bright fluting in the violet; the continuous spectrum extended from D to a little beyond the band at wave-length 474.

Examining the spectrum of Swift's Comet (1892. i.), Konkoly found five lines which he gave [m] in the following

[l] *Nature*, vol. xlii, p. 112. May 29, 1890.

[m] *Ast. Nach.*, vol. cxxix, No. 3087. April 25, 1892.

order of intensity:—5163·0, 5588·2, 5449·4, 4725·4, and 4687·8; this was on April 1 and 2, 1892. But Campbell examining the same object on April 5 saw [n] quite a different spectrum, consisting of the characteristic bands 5630, 5170·3, and 4723, with the relative intensities 1, 6, and 2. The wave-length of the middle band appeared to vary, and Campbell suggested that three bright lines formed at wave-lengths 5170, 5164, and 5157, and disappeared in that order. If this were a real change between April 1 and April 5, it is significant to note that the perihelion occurred on April 6, but Campbell's measures were not sufficiently delicate to detect any such change about that time. Von Gothard photographed the spectrum of this comet with the spectrum of a Bunsen flame on the same plate, and found the two to be identical as far as the fourth band (473–464) [o]. Beyond that, new unknown lines and bands appeared and the band at 389–387 was faintly represented. The new bands were similar in appearance to the hydro-carbon bands, and this led Von Gothard to the conclusion that the hydro-carbon in comets is different, or exists under different conditions, from that appearing in the Bunsen flame.

The next comet of importance to which reference must be made was Holmes's, discovered on November 6, 1892, and described generally elsewhere.[p] This was a remarkable body, a diffuse, nebulous, tailless mass easily confounded with the Andromeda nebula; and its spectrum was just as peculiar. Instead of the usual display of bands Keeler [q] saw simply a fairly bright, continuous spectrum extending from D to about half-way between F and G, the maximum brightness being a little below *h*. Careful scrutiny failed to reveal any lines, and the nucleus was seen as a brighter streak running through the whole spectrum. Observations made by Campbell [r] on November 8 and 9, 1892, showed a spectrum "of an extreme type and probably unique", a continuous spectrum, extending

[n] *Astronomy and Astrophysics*, vol. xi, p. 698. Oct. 1892.

[o] *Eder's Jahrbuch*, 1893.

[p] p. 74 (*ante*).

[q] *Astronomy and Astrophysics*, vol. xi, p. 929. Dec. 1892.

[r] *Ibid.*, vol. xii, p. 57. Jan. 1893.

from D to G, with a very slight condensation evidently due to the familiar green band at wave-length 515, and a very faint trace of the yellow band. Keeler examining the spectrum again on January 29, 1893, after an anomalous brightening of the comet on January 16, saw a very faint suspicion of the green band of which he could never be certain.[s]

The spectrum of a strongly moonlit sky was exactly similar to, but fainter than, that of the comet. It would appear then that in this case they were dealing with an object almost wholly illuminated by reflected light. It had been suggested that this peculiar comet might have been formed by the collision of two asteroids, but, as Keeler pointed out, the observed spectrum negatives this hypothesis; such a cataclysmic birth would involve the production of a bright line, or banded, spectrum.

The spectrum of Rordame's Comet (1893, ii.) was very fully investigated, photographically, by Campbell,[t] who measured 28 bright lines, 14 of which were found to correspond with lines and bands given by Kayser and Runge in the spectra of carbon and cyanogen.

Visual observations by Keeler[u] showed that the spectrum was a beautiful example of the hydro-carbon type, and he called special attention to the sharpness of the bands at their less refrangible edges, a phenomenon not usually seen in cometary spectra.

The spectrum of the Comet 1902 (ii.) (Perrine-Grigg's) was of special interest, because it was in photographing this that Count De La Baume-Pluvinel first employed the short-focus prismatic camera, now recognised as a *sine quâ non* in the photographic recording of the spectra of faint comets.

Experiments with larger instruments having proved fruitless, Baume-Pluvinel built up a camera[v] wherein the focal length of the objective was but four times the aperture, and to which he applied a prism of 20° refracting angle. Of

[s] *Astronomy and Astrophysics*, vol. xii, p. 272. March 1893.

[t] *Ibid.*, vol. xii, p. 652. Aug. 1893.

[u] *Ibid.*, vol. xii, p. 650. Aug 1893.

[v] *Bull. de la Soc. Ast. de France*, vol. xvii, p. 117. March 1903.

course the negatives obtained with such an instrument are practically useless for the fine determination of wave-lengths, but they are capable of showing the qualitative variations and coincidences of cometary radiations.

The spectrum obtained, with one hour's exposure, by Chrétien and Senoque, showed the three characteristic bands 564, 518, and 472, and the cyanogen band at 389. Almost all the light of the comet was concentrated in the two bands 472 and 389, and Baume-Pluvinel remarks, parenthetically, that objectives intended for comet photography should, obviously, be especially corrected for this more refrangible region of the spectrum. The heads of the bands at 564 and 518 were bright visually, but were much fainter, relatively, on the photograph, although orthochromatic plates were used. It is most essential that this difference of photographic and visual intensities should be carefully considered when comparing the relative intensities of spectral lines.

The spectrum of Borelly's Comet of 1903 (iv.) was photographed by Deslandres [x] at Meudon, and found to be similar to that of Rordame's Comet obtained by Campbell in 1893.

Perrine [y] also found the same five bands in the spectrum of this comet as were recorded by Campbell in that of Rordame's Comet, but noticed that the band at 420 was much weaker relatively. Curtis also recorded the similarity with Rordame's, and noted a strong continuous spectrum.

In 1904, Pickering employed an objective-prism camera to photograph the spectrum of Brooks's Comet (1904, i.) which he found to be nearly continuous, with two slight condensations.

The success of the prismatic camera as an engine of research in the investigation of cometary spectra soon led to its more general application, so that on the appearance of Daniel's Comet of 1907 (iv.) several observers employed it to obtain photographic records of the comet's radiations. A great advantage of spectra thus obtained (in that they show monochromatic images of all the sufficiently bright parts of the

[x] *Comptes Rendus*, vol. cxxxvii, p. 393. Aug. 17, 1903.

[y] *Lick Observatory Bulletin*, No. 47. 1903.

comet) was amply affirmed, for on spectra obtained by Mr. and Mrs. Evershed,[z] at Kodaikanal, India, and by Deslandres,[a] at Meudon, it was found that the radiations of the nucleus were not identical with those of the tail. Evershed photographed the spectrum of Procyon alongside that of the comet, and was thus able to determine the wave-lengths of the cometary spectrum by direct comparison with the hydrogen lines in that of the star.

The last comet to be considered here is the one discovered by Morehouse on September 1, 1908.

No other comet has ever been so well, and so persistently, observed, and certainly no other cometary spectrum ever received so much detailed attention. Whilst the object itself was remarkable for its vagaries, its lightning changes of form, and its periodic outbursts, the spectrum observations were, at first sight, almost as remarkable for their positive disagreements. This may have been due, however, to some extent, to the fact that so many observers were at work at different times.

Count De La Baume Pluvinel and Baldet[b] photographed the spectrum, with the prismatic camera, on October 4, 5, and 7. The plates obtained showed seven monochromatic images of the comet and indicated that the hydrocarbon radiations—strong in the spectrum of Daniel's Comet, obtained with the same instrument—were absent: the cyanogen spectrum, usually represented by the band at 388 alone, was completely represented in the part of the spectrum photographed, and there was no trace of continuous spectrum.

Evidence of change was afforded by the radiation at 376, for whilst a tail accompanied the feeble image photographed on October 5, there was no trace of it on the more intense, nuclear image of October 7.

Deslandres and Bernard[c] agreed on the absence of the hydrocarbon radiations. But they found the two first heads

[z] *Monthly Notices R.A.S*, vol. lxviii, p. 16. November 1907.

[a] *Comptes Rendus*, vol. cxlv, p. 445. Aug. 26, 1907.

[b] *Comptes Rendus*, vol. cxlvii, p. 666. October 19, 1908.

[c] *Comptes Rendus*, vol. cxlvii, p. 774. November 2, 1908.

of band at 388 to be the only representatives of the cyanogen spectrum, and recorded a very persistent continuous spectrum. The three strongest bands of unknown origin were those at 456·1, 426·7, and 401·3 previously recorded by Evershed in the spectrum of Daniel's Comet.

Another similarity of these two comets was found in the fact that some of the bands were double.

The results obtained by Frost and Parkhurst,[d] at the Yerkes Observatory, exhibited points of variance with both sets of the French observations. Twenty-one spectrograms were obtained between October 28 and December 2, 1908, and on none was there a trace of continuous spectrum, thus showing that at that epoch the amount of reflected sunlight was very small as compared with the amount of intrinsic light emitted by the incandescent carbon and other matter. [See Fig. 101, Plate XXVI.]

Allowing for the uncertainty of wave-length measures made on photographs of small dispersion, it appears that both the hydrocarbon and cyanogen spectra are probably represented. Relative variations in the intensity of the tail images indicate some difference between nuclear and tail matter which is not explained by the behaviour of the matter concerned when experimented upon in the laboratory.

An important feature of these spectra is that the separate monochromatic images of the tail follow the bends seen on the direct photograph, thus showing that particles having the same chemical constitution were ejected at angles differing by as much as 40°. Apparently we have, in this, a contradiction of Bredichin's theory, according to which the comparatively straight tails shown on these photographs should have been seen only in hydrogen radiations and not in those of the hydrocarbons and cyanogen.

Campbell and Albrecht[e] made visual and photographic observations, using, for the latter, a specially designed spectrograph in conjunction with the 36-inch Lick refractor. Their results showed the presence of carbon and cyanogen, although the second cyanogen band was, apparently, entirely absent.

[d] *Astrophys. Journ.*, vol. xxix, p. 55. Jan. 1909.

[e] *Astrophys. Journ.*, vol. xxix, p. 84. Jan. 1909.

MOREHOUSE'S COMET (1908, iii.). December 11.

PHOTOGRAPH AND SPECTROGRAPH OF MOREHOUSE'S COMET (1908, iii.).

In a communication[f] to the Paris Academy of Sciences, Deslandres, Bernard, and Bosler epitomised and discussed the various observations of this comet, drawing therefrom some valuable conclusions.

They pointed out that prior to 1907 the only cometary tail spectrum observed was that of the great Comet of 1881, in which the "Swan", or so-called "hydrocarbon" spectrum, was recognised. But in the tails of Daniel's and Morehouse's Comets, new radiations at 456, 426, and 401 were discovered. Also, they disagree with Baume Pluvinel's partition of lines into series.

The presence of a band at 3913·2, recognised as belonging to the spectrum of nitrogen at low pressure, and produced by cathode rays, suggests that the cometary matter may be rendered incandescent by the passage of cathode rays emitted by the Sun.

These observers consider that the new spectrum of doublets, and its three principal radiations at 456, 426, and 401, probably constitute the most constant character of cometary spectra, for they appear as intense radiations in the Daniel and Morehouse Comets in which the classical carbon bands showed marked variations.

Thus we see that more recent researches have not tended to simplify the question as to the nature of cometary spectra. Besides the older conception of "hydrocarbons", cyanogen, and reflected sunlight, we have many new lines, probably indicating other substances, to be investigated. But that carbon in one form or another plays an important part in the constitution of comets, is certain; and we now know that in recent comets the cyanogen radiations, especially that at 388, have taken up a large proportion of the comet's light. The ultra-violet character of the light from Morehouse's Comet was a very strong feature which becomes important when we consider the problem of comet photography.

Morehouse, who discovered it by photography, described it as having a conspicuous tail; Borelly, who found it independently, and visually, could see scarcely any tail. An

[f] *Comptes Rendus*, vol. cxlvii, p. 805. March 29, 1909.

observer with eyes sensitive to these more refrangible rays would probably have seen this comet as a brilliant naked-eye object.

The important part played by cyanogen in the spectra of comets, considered in conjunction with solar and laboratory observations of the cyanogen spectrum, led Newall to propound the following interesting questions concerning the nature and origin of cometary radiations.[g] "Is it not possible that the hydrocarbons, nitrocarbons, etc., which seem to be evidenced by the spectra of all comets, are *always* present in circumsolar space, and rendered incandescent by some processes connected either with the motion of the solid parts (including dust) of the head of the comet through the vapours, or with the emission of some influence from the comet head? Are we to say that all comets, wherever they may come from in the universe, and whatever their main material may be, always bring with them the cyanogen and hydrocarbons which give them luminosity? Or is it not more rational to say that the spectra of all comets are approximately similar, because they always find the same vapours spread in their path as they approach the Sun, and can only elicit the spectra of these vapours?"

The author of this interesting theory has evidence of the existence of cyanogen between the Sun and the Earth's surface, and has worked out at some length the conditions under which the luminosity could be generated. But for the present, despite the delightfully simple way in which such a theory would explain the similarity of cometary spectra in general, we must be content to look upon the comet spectrum as radiation, probably produced by electrical action of some kind, from the particles of the comet itself. That the volatile gases of the carbon compounds should be the first to be excluded is not a matter of wonder, whilst the observation that when the comets attain to lesser distances from the Sun, and therefore become more strongly heated, both by the solar radiation and by the increased number of collisions among their own particles, sodium and iron are vaporised and

[g] *Monthly Notices R.A.S.*, vol. lxviii, p. 5. Nov. 1907.

rendered incandescent, is but another step in accordance with the law of continuity.

Schiaparelli and others have taught us to associate closely meteors with comets, and we now know of numerous instances in which a comet and a meteor stream are actually travelling on the same orbit. It might be expected that there would be some resemblance between the spectra of the two classes of bodies. But the rapid motion and evanescent character of meteors makes their spectroscopic observation exceedingly difficult. Browning, however, succeeded in observing no fewer than 70 in August and November 1866, with an instrument constructed by himself for the purpose.[h] This consisted simply of a direct-vision compound prism, and a plano-concave cylindrical lens; the latter being intended to diminish the apparent angle through which the meteors fell. The heads of the meteors gave spectra mostly continuous, though with frequent differences in the relative preponderance of the colours. In the tails, in every instance, orange-yellow light predominated, from which the presence of sodium may probably be inferred. Konkoly looks upon this presence of the sodium line as possibly due rather to particles floating in our air and becoming incandescent with the meteor than to any constituent of the meteor itself. But the same observer in the spectrum of a magnificent fireball on Oct. 13, 1873, observed not merely the sodium lines, but also bands which he was able to identify by direct comparison with the spectrum of a hydrocarbon,[i] thus affording an evidence from the spectroscopic side of the connection between comets and meteors; and remembering the brilliant sodium lines of the comets of 1882, it does not seem improbable that meteors should show this metal also.

Other metallic lines have also been observed in meteors: those of Magnesium frequently, and the lines of lithium and potassium sometimes.

[h] *Month. Not. R.A.S.*, vol. xxvii, p. 77. Jan. 1867.

[i] *Month. Not. R.A.S.*, vol. xxxiv, p. 82. Dec. 1873. The word "lightning gas" is a misprint for "lighting gas", that is to say, coal gas.

CHAPTER XIII.

THE RELATION OF COMETS TO METEORS.

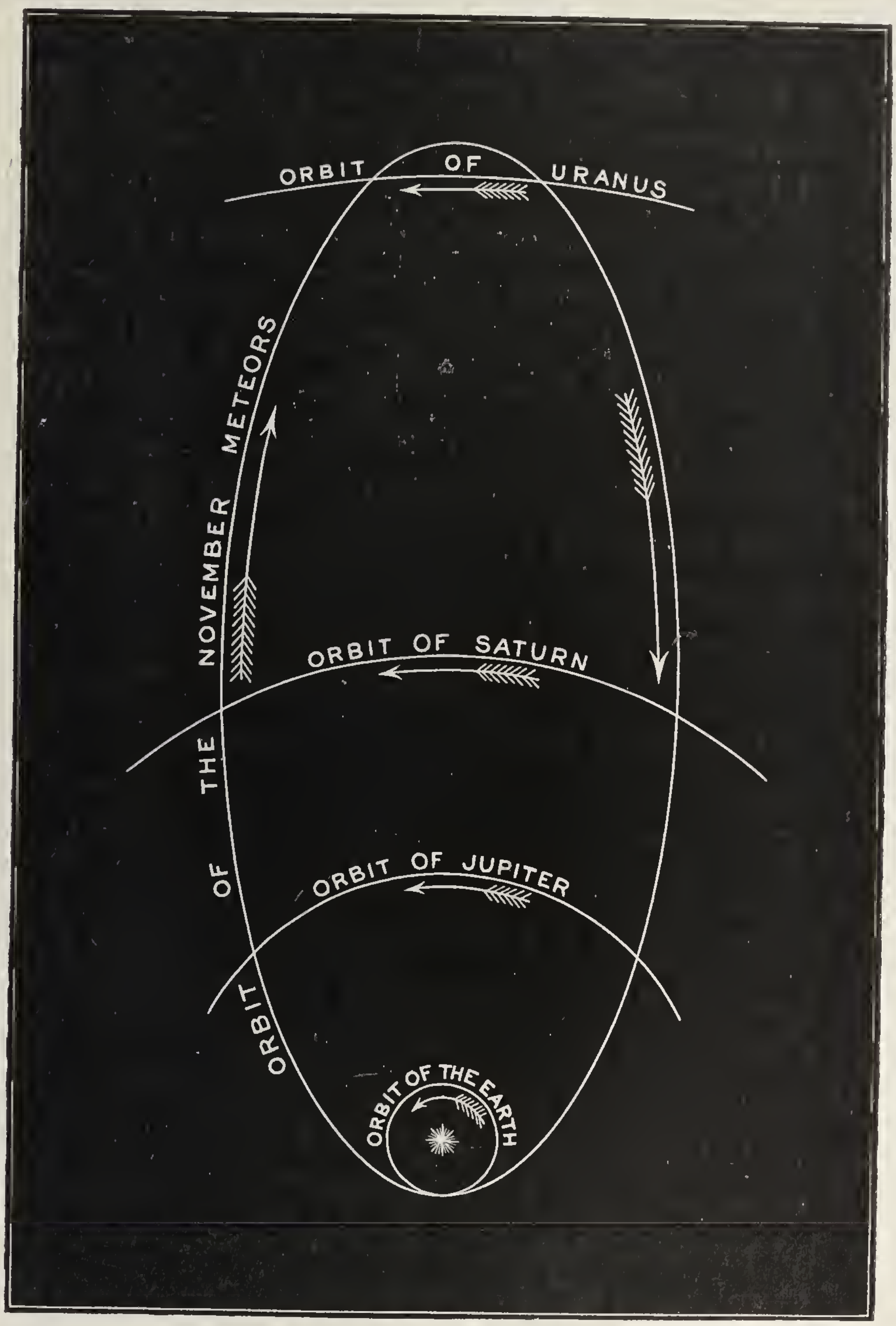
Association of Comets and Meteors.—Facts connected with Meteors necessary to be borne in mind.—Summary statement of these.—Meteor Showers of 1799 *and* 1832.—*Shower of* 1866.—*Evident periodicity.—Researches of Quetelet and H. A. Newton.—Investigations by J. C. Adams.—Schiaparelli and the August Meteors.—Orbits of certain Meteor Swarms identical with the Orbits of certain Comets.—Four such cases of identity recognised.—The August, or Perseid, Meteors.—The Nov.* 12, *or Leonid, Meteors.—The April, or Lyrid, Meteors.—The Nov.* 27, *or Andromedes, Meteors.—The disappearance of Biela's Comet.—The certainty of the connection of the Andromedes Meteors with that Comet.—Recent investigations as to that Comet.—Review of the whole subject.*

Not the least interesting of the modern developements of Cometary Astronomy is the discovery that in certain cases a relation exists between comets and meteors. Time was, not so very long ago, when comets were considered (and rightly) matters of pure Astronomy, whilst meteors of all kinds, the so-called "shooting stars" included, were looked upon as belonging to the domain of terrestrial Meteorology. How the association came to be known needs to be told in a book dealing with the matter from the astronomical side, but, as I desire to avoid going more deeply into the subject of meteors than is absolutely necessary, I must ask the reader to take on trust a few facts baldly stated, referring him to other works for details.

The facts contemplated in the foregoing remark are the following: (1) shooting stars may be seen on almost every night of the year in some part of the heavens; (2) they are more numerous at certain seasons of the year than at others; (3) whilst odd ones may often be noticed anywhere, so to

speak, there are about 100 or more particular centres in the heavens which are specially centres from which they seem to radiate; (4) the meteors coming from these centres are named

Fig. 102.



ORBIT OF THE LEONIDS OF NOV. 13 AND OF THE COMET OF 1866 (i.) RELATIVELY TO THE ORBITS OF CERTAIN PLANETS.

by ugly fabricated names derived from the constellations in which the centres are situated; thus *Leonids, Lyrids, Perseids, Quadrantids,* and so on; (5) the term "shooting star" is an old-fashioned one which has almost gone out of use, having

been replaced in scientific circles by the term "luminous meteor", or simply "meteor". This summary will suffice as a preface to what is to follow.

In Nov. 1799, and 34 years afterwards, namely, in Nov. 1833, there happened magnificent displays of luminous meteors, radiating from a point in the constellation Leo, whence they have obtained the name of *Leonids*. Drawing the conclusion, from a catalogue of such displays which had been formed by a Belgian astronomer named Quetelet, that these displays were periodic at stated intervals, an American astronomer named Newton (following up some previous investigations by two learned Americans, Olmsted[a] and Twining, of New Haven, Connecticut) entered upon a thorough investigation of the subject with a view of ascertaining whether any prediction as to future displays could safely be put forth. He came to an affirmative conclusion by announcing that another great display would occur on Nov. 14, 1866; in other words, that these displays were undoubtedly periodic, and that the period was about 33¼ years. The display duly happened as Newton had predicted, and was a very beautiful one; but we are not here concerned with any descriptive details,[b] except to say that a repetition of the show on a much smaller scale occurred in 1867; and that the swarm is so stretched out that it seems to take more than 3 years in passing a given point in its orbit whilst crossing the Earth's orbit. Another great display was expected in 1899 or 1900 but did not occur, though in November 1898 and November 1901 considerable displays did take place.

Taking advantage of the information which had been gathered by previous workers in this field, Professor J. C. Adams, of Cambridge (of Neptune fame), proceeded to calculate elliptic elements for the orbit of the meteor swarm treated as, in a sense, a concrete mass.[c]

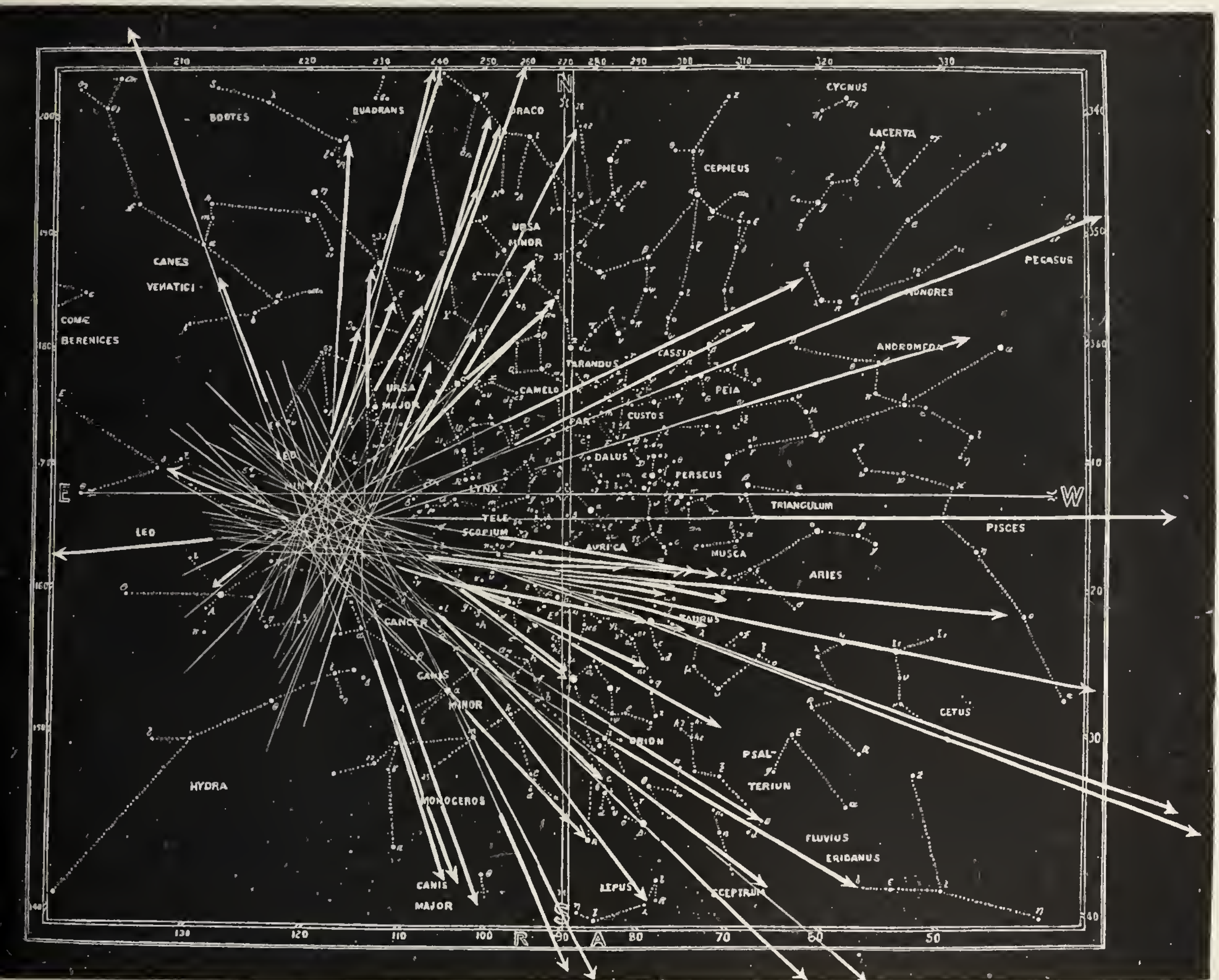
[a] Olmsted seems indeed to have broached as far back as 1834 the idea that the shower of 1833 had something cometic about it. (*Silliman's American Journal*, vol. xxvi, p. 172.)

[b] See my *Handbook of Astronomy*, vol. i, p. 616, *et seq.*

[c] *Month. Not. R.A.S.*, vol. xxvii, p. 247. April 1867.

Postponing for the moment Adams's conclusions we will pass on to some researches carried out on kindred lines by Schiaparelli of Milan. He took in hand the Perseid meteors of August as he found them recorded on Aug. 9, 10, 11, 1866; and treating them also as a concrete mass and assuming, as

Fig. 103.



THE METEOR RADIANT POINT IN LEO: TRACKS OF METEORS SEEN AT GREENWICH, NOV. 13, 1866.

Adams had done, that their orbit was a section of a cone, he arrived at certain figures on the supposition that the conic section in question was a parabola. He had reached this stage in his researches when he suddenly discovered that his parabolic elements of the meteor group very closely resembled the elliptic elements which had been obtained for the Comet

of 1862 (iii.). The resemblance will be best seen by putting the two sets of figures side by side thus :—

	August Meteors.	*Comet of* 1862 (iii.).
Perihelion passage	1862, July 13	1862, Aug. 22. 9
Longitude of perihelion	343° 28′	344° 41′
Ascending node	138° 16′	137° 27′
Inclination of orbit	64° 3′	66° 25′
Perihelion distance	0·9643	0·9626
Period	105 years ?	123·4 years
Direction of motion	Retrograde	Retrograde

Whilst it must be admitted that the estimate of the periods is uncertain the general resemblance of the other elements of the two orbits is too unmistakable to permit of any doubt being thrown on the fact that meteors and comet were moving in orbits identical in form. The return of this meteor-comet is to be looked for in 1985.

Now we must go back to a consideration of Adams's results, and they follow the precedent established by Schiaparelli; for the elements of the November meteors (treating their orbit as an ellipse) were found reproduced almost precisely in the elements of the Comet of 1866 (i.) as found by Oppolzer. Adams presented them in the following form :—

Period	33·25 years (assumed)	33·18
Mean distance	10·3402	10·3248
Eccentricity	0·9047	0·9054
Perihelion distance	0·9855	0·9765
Inclination	16° 46′	17° 18′
Longitude of node	51° 28′	51° 26′
Distance of perihelion from node	6° 5′	9° 2′
Direction of motion	Retrograde	Retrograde

A separate group of the *Leonids* is also suspected to exist, preceding the principal one by about 12 years (or about $\frac{1}{3}$rd of a revolution) in its appearance. Notable meteor showers are recorded to have taken place in 855–56, 1787, 1818–23, and 1852, agreeing exactly with the principal cluster in the day and very closely also in the period of their returns.[d] The original dismemberment of the comet (assuming that a comet was in question) to which the ancient record of this widely

[d] *Nature*, vol. xi, p. 407, March 25, 1875; vol. xii, p. 85, June 3, 1875.

scattered cluster points must have been of great antiquity, since the interval of 12 years between the years 855–56 and the next display in 868 differs very much from the distance found to separate in modern times the well-marked minor apparitions of the years 1787, 1820, and 1822 compared with the modern appearances of the chief group in 1799 and 1833. It may, therefore, be assumed that important consequences may sooner or later be expected to be traced as the outcome of investigations in this field of cosmical phenomena, for it cannot be supposed that we have reached yet by a long way the end of our tether in our knowledge of these subjects. The next return of the Leonid meteor-comet is expected in the summer of 1932.

It was subsequently found that the meteor shower belonging to the date of April 20, and now known as the Lyrids, matched, as regards their orbit, the Comet of 1861 (i.), whilst the shower of Nov. 27, now known as the Andromedes, similarly matched the orbit, as known up to that date, of the missing Comet of Biela. There is not much to be said about the Lyrids and their attached comet, but as regards the Biela association a long tale can be unfolded.

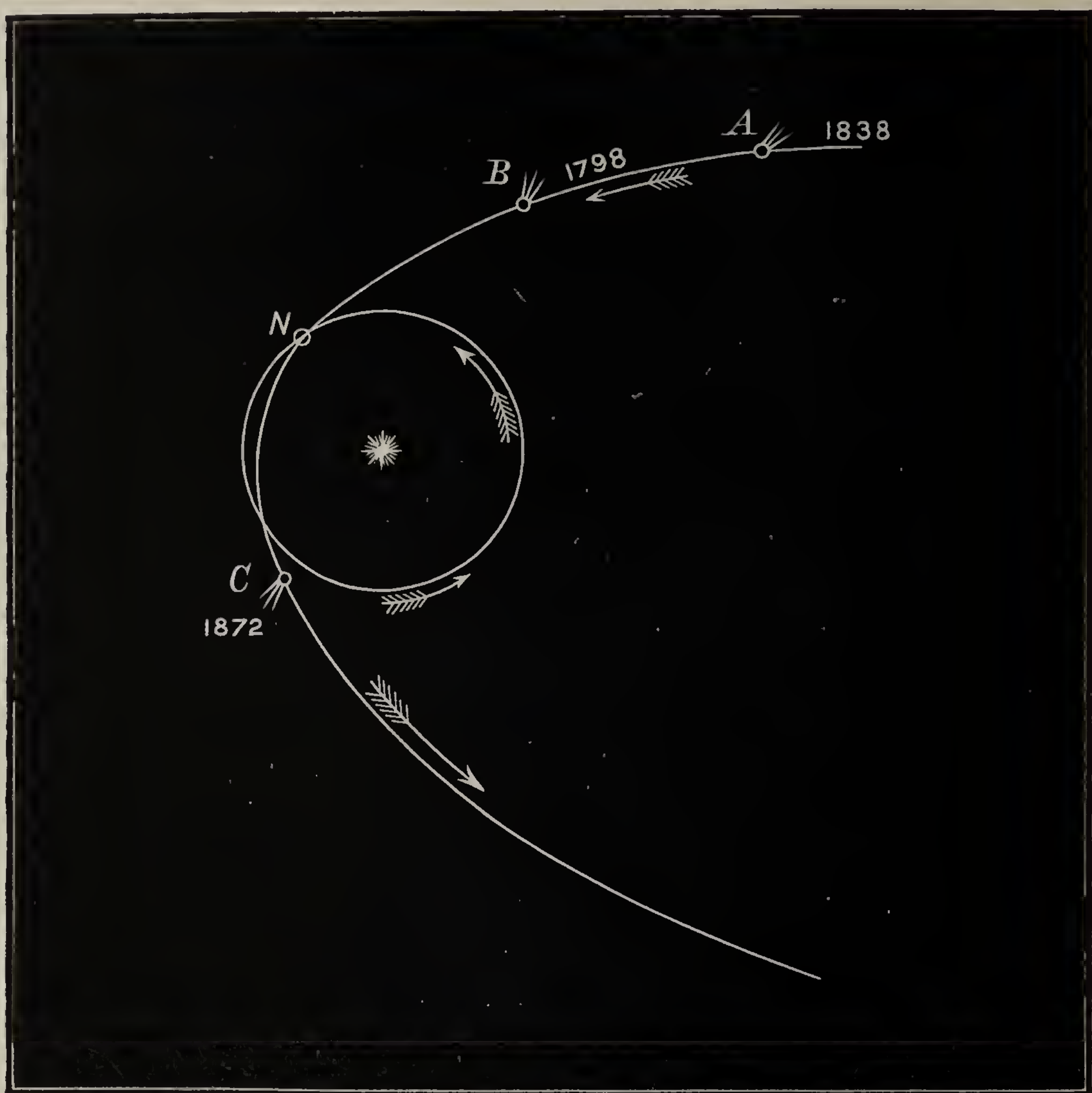
When things had reached the stage of developement which has just been described, it naturally came into men's minds, could the newly-acquired knowledge be brought to bear in any way in elucidating the mystery of the disappearance of Biela's Comet,[e] which at that time was an unprecedented and wholly inexplicable mystery? It was possible to give an affirmative answer to the question. Though this comet had failed to appear either in May 1859, or in Jan. 1866, hopes were entertained that it might be picked up when next due, which would be in Aug. and Sept. 1872, the perihelion passage having been fixed for Oct. 6. These hopes were not realised, but the appearance on Nov. 27, 1872,[f] of an abundant meteor shower corresponding in the position of its radiant point, and in the date of its appearance, with the position and date of a meteor

[e] See p. 88 (*ante*).

[f] This date may be taken to represent as from 1859 two complete revolutions of Biela's Comet assumed to have a period of 6·5 years.

stream following directly in the track which Biela's Comet should have followed, and 12 weeks after the comet's calculated departure from the place, corroborated the inference, already drawn from the previously known examples of agreements, that a rich assemblage of meteors moving in the rear of a cometary body *follows* the comet very closely in its

Fig. 104.



POSITION OF BIELA'S COMET AT THE TIME OF THE METEOR SHOWERS OF 1798, 1838, AND 1872.

orbit. The conclusion now seems recognised as inevitable that Biela's Comet has ceased to exist as a concrete body. What has just been stated appears, however, to be only a portion of the truth, for showers of Andromedes seen in 1798, 1830, and 1838 would seem to have *preceded* Biela's Comet along its track at different distances varying between $\frac{1}{20}$th and $\frac{1}{3}$rd of a circuit.

Fig. 104 gives, according to H. A. Newton, the positions of Biela's Comet in its orbit relatively to the Earth at the times of the occurrence of the great meteor showers known to have been manifested when the Earth was near this comet's orbit. The line of the nodes, or the place of the Earth's nearest approach to the comet's track, being at N, it appears that in 1798, when the Earth encountered at that point the great meteor shower of Dec. 6 of that year, observed by Brandes, Biela's Comet was at B, somewhat nearer to the Earth than in 1838 on the next occasion when a similar display was witnessed. In the last-named year the comet was at A, about 300 millions of miles distant along its orbit from the Earth. At the recurrence of the great meteor shower of Nov. 27, 1872, the comet must have been near C, or about 200 millions of miles along its path from the node N. From this it would seem that the meteoric particles must be thickly distributed over a stretch of at least 500 millions of miles of the comet's orbit, preceding the comet "to a distance of 300 millions of miles, and following it to a distance of 200 millions of miles, as in 1872[g]."

If Biela's Comet had maintained its existence it would have reappeared in 1879, 1886, 1892, 1899, and 1906. It has been suggested that in the years in which it would have been due the Andromedes meteors were more pronounced than in ordinary years, but I have not found sufficient evidence to support this idea.

One case of a meteor shower pairing off with a comet in the way above described might have been a mere coincidence; but four clear cases set astronomers thinking that there was something important in the background. That something is that all meteor showers are manifestations of broken-up comets. This may be the case, but it is premature at present to assert this dogmatically. Probably it may be safely assumed that the more scattered a meteor shower is the longer

[g] H. A. Newton, *Brit. Assoc. Report*, 1875, p. 224. For further information respecting Biela's Comet in connection with meteors, see papers by A. S. Herschel, *Month. Not. R. A. S.*, vol. xxxii, p. 355, 1872; and by Denning, *Month. Not. R. A. S.*, vol. lxv, p. 851. June 1905.

it has been attached to the solar system; and if it is really of cometic origin, the longer is the time that has elapsed since the catastrophe happened to the comet. As the Perseids are a very scattered group, perhaps they have been long in our system; but the Leonids and the Andromedes may be much more modern introductions if weight is to be attached to Le Verrier's conclusion that it was a *rencontre* of Tempel's Comet of 1866 (i.) with the planet Uranus, in the year 126 A.D., which brought that comet under the permanent influence and control of the Sun.

From what has gone before it will be readily realised that the two great meteor showers of November (12th and 27th as they may be summarily styled) are very certain in their cometary relations, but the same cannot be said in quite such positive terms of the Lyrid shower of April, nor of the Perseid shower of August. In the two first-named instances the periodical returns of the meteors yielding special displays have occurred at the predicted times, and the periods of revolution of comets and meteors respectively are clearly identical. But the same cannot be affirmed of the April and August systems, because the periods are open to considerable uncertainty owing to the orbits being of far greater eccentricity.

Kirkwood is responsible for the definite statement of another comet-meteor alliance. He says :—" The identity of the comets of 1866 [i.] and 1366, first suggested by Professor H. A. Newton, is now unquestioned. The existence then of a meteoric swarm, moving in the same track, is not the only evidence of the original comet's partial dissolution. The Comet of 1866 was invisible to the naked eye; that of 1366, seen under nearly similar circumstances, was a conspicuous object. The statement of the Chinese historian that 'it appeared nearly as large as a tow measure', though somewhat indefinite, certainly justifies the conclusion that its magnificence has greatly diminished during the last 500 years. The meteors moving in the same orbit are doubtless the products of this gradual separation." [h]

How far we are justified in generalising on the whole sub-

[h] *Comets and Meteors*, p. 52.

ject is an interesting question which must be handled with discretion. There is no doubt that the trend of scientific opinion is in the direction of suggesting that comets furnish the numerous meteors which traverse space and frequently manifest themselves to us on the Earth; and to Schiaparelli must be given the credit of first demonstrating the connection. Sir N. Lockyer goes beyond this, for in his view comets are naught else but immense aggregations of meteors, and naturally if they throw off anything it is meteoric particles which they throw off. It must, however, be confessed that the subject has not made much progress of late, notwithstanding the great number of comets which have appeared during the last 20 years, coupled with the multiplication of observers and observations of luminous meteors.[i]

Though to Schiaparelli the leading place of honour has been given in the foregoing pages, the meritorious labours must not be ignored of several other astronomers who cleared the way and furnished many of the materials the utilisation of which led to the actual discovery. Thus in 1861, several years before Schiaparelli began his labours, Kirkwood broached the theory that "meteors and meteoric rings are the *débris* of ancient but now disintegrated comets, whose matter has become distributed around their orbits".[k] And writers even earlier than Kirkwood had expressed ideas not materially different; but unfortunately they could not command the data required to give practical support to their views, which were in consequence disregarded as idle speculations.

J. Glaisher well summed up the matter in saying that "The intimate connection now known to exist between comets and meteors is perhaps the most striking and novel discovery of a purely astronomical kind that has been made in our time", with the exception (I think I should like to add) of the discovery of Neptune.

[i] More than 30 years ago A. S. Herschel put forth a long list of 75 suggested coincidences, but it does not appear that either he or anybody else followed them up. *Month. Not. R. A. S.*, vol. xxxvi, p. 220, Feb. 1876; *ibid.*, vol. xxxviii, p 369. May 1878. Denning informs me (and he is a high authority) that there is no sufficient proof of the connections which A. S. Herschel shadowed forth.

[k] *Danville Quarterly Review*, Dec. 1861.

CHAPTER XIV.

COMETS IN HISTORY AND POETRY.

Comets, objects of terror and alarm in all ages.—Opinions of the ancient Greeks.—Of Anaxagoras.—Of Democritus.—Of Apollonius and Zeno.—Sir G. C. Lewis's Summary of Greek Opinion.—Ptolemy silent as to Comets.—Twelve varieties mentioned by Pliny.—Opinions of Seneca.—Of Paracelsus.—Napoleon and Comets.—The Romans not given to Astronomy.—Quotations from Virgil.—From Suetonius.—From Juvenal.—From Pliny.—From Plutarch.—Opinions of the old Chroniclers.—Quotation from William of Malmesbury.—Pope Calixtus III. and the Comet of 1456.*—Admiral Smyth on this matter.—Leonard Digges.—John Gadbury.—Shakespeare's frequent mention of Comets.—Quotation from* Julius Cæsar. *—From* Henry VI.*—From* Hamlet.*—From* Henry IV.*—From* The Taming of the Shrew.*—Quotations from Milton.—Milton apparently a plagiarist from Tasso.—Quotation from Thomson.—From Pope.—From Lord Byron.—From Young.—Some modern Poetry.—An American Incident.—Comets and Hot Weather.—The Earl of Malmesbury.—Arago rebukes wild speculations.—French writers.—Fontenelle.—Lambert.—Supposed allusions in the Bible to Comets.—Maunder's opinion.*

Already in my first chapter have I called attention to the fact that comets have at all times been a source of great interest to the world in general, but it will be worth while to pursue the matter and rake up some of the historical notices of comets from the early times down to the Middle Ages and later; with a glance now and again at what some of the great poets have said on the subject.

Going back to the times of the earliest known students of Astronomy—the Chaldæans, it is to be noted that they seem to have considered comets as analogous in their nature to planets; that is to say permanent bodies revolving round the Sun in orbits, so much more extensive, however, that they were only visible when they came near the Earth. This opinion, which is the oldest hint we have of the existence of periodical comets, was also held by philosophers of the Pythagorean School.

It is well known that many celebrated Greek philosophers paid much attention to astronomical phenomena, and therefore to comets amongst other things. Anaxagoras explained comets to be produced by the concourse of planets and by their combined splendour. Democritus of Abdera, following Anaxagoras, conceived that comets were the result of a concourse of certain planetary stars. Apollonius and Zeno are reputed to have upheld very similar ideas, but these two are not quoted by Sir G. C. Lewis, the most modern chronicler of ancient scientific ideas.[a]

Lewis's summary of Greek opinion is so conveniently concise that I make no apology for transcribing what he said. "Comets were the object of much speculation among the early Greek astronomers; the opinions of Anaxagoras and Democritus, of the Pythagoreans, and of Hippocrates of Chios, and of his disciple Æschylus, respecting them, are reported and analysed by Aristotle. Differing in other respects they agreed in considering the comets to be planets. Against this general position, Aristotle argues by saying that the planets are always confined within the zodiacal band; whereas many comets have been seen without these limits, and it has often happened that more than one comet has been visible at the same time. He points out further, that some of the fixed stars have been seen with a tail. For this fact, he refers to the general report of the Egyptian observers: he adds, however, that he had himself seen a star in the leg of the constellation Sirius, with a faint tail. He states that it could scarcely be seen if the vision was fixed directly upon it, but it was more visible if the sight was turned slightly on one side. Against the theory that comets were a congeries of planets, he remarks that all those which had been seen in his time disappeared without setting, while they were still above the horizon: they faded away gradually, and left no trace either of one planet or several. He adds that the great comet in the Archonship of Asteius (373 B.C.) appeared in the winter, in a clear sky: on the first day it was not visible,

[a] *Historical Survey of the Astronomy of the Ancients*, 8vo. London, 1862, pp. 106, 140, 168.

because it set before the Sun; on the second day it was seen imperfectly, for it set immediately after the Sun in the west; its brightness extended over a third part of the sky: it reached as far as the belt of Orion, and there ceased. Aristotle points out that a concourse of stars does not constitute a comet. The Egyptian astronomers, he says, report that conjunctions of planets, both with one another, and with fixed stars, occur. He himself had observed Jupiter, in the constellation Gemini, on two occasions, coming into conjunction with a star, and occulting it, but without assuming the appearance of a tail. Aristotle himself thinks that comets are in the nature of meteors, and that their range is in the region nearest the earth." [b]

The greatest Greek author of antiquity, HOMER, in the *Iliad*, says:—

[The helmet of Achilles]
ἡ δ', ἀστὴρ ὣς ἀπέλαμπεν
Ἵππουρις τρυφάλεια, περισσείοντο δ' ἔθειραι
Χρύσεαι, ἃς Ἥφαιστος ἵει λόφον ἀμφὶ θαμειάς.

Thus rendered by Pope:—

[The helmet of Achilles shone]
"Like the red star, that from his flaming hair
Shakes down diseases, pestilence, and war."
(*Iliad*, Bk. XIX, ll. 380–3.)

Pope has evidently borrowed from Milton, as below.

It is a somewhat remarkable fact that Ptolemy, so celebrated for his varied astronomical attainments, should nowhere have made any mention of comets, but seemingly that was because he regarded them as objects terrestrial, not celestial. On the other hand, Pliny appears to have paid much attention to them, if we may judge by the fact that he enumerates 12 varieties, each kind receiving its name from some physical peculiarity of the objects belonging to it.

Hevelius gave sketches of 11 of Pliny's 12 forms, and their titles as follows:—

Disci: disciformis	= discs.
Pithei: doliiformis erectus	= like an upright cask.

[b] G. C. Lewis, *Astronomy of the Ancients*, p. 168.

Hippei: equinus barbatus	=	like a horse's mane.
Lampadiæ: (2) lampadiformis	=	torch-shaped.
Barbatus	=	bearded.
Cornutus bicuspidatus	=	double-pointed.
Acontiæ: faculiformis lunatus	=	like a small torch.
Xiphiæ: ensiformis	=	sword-shaped.
Longites: hastiformis	=	spear-shaped.
Monstriferus	=	horror-producing.

It seems a pity that so much romance in the way of classification should have been lost to astronomy and wasted on meteorology!

Seneca considered that comets must be above (*i.e.* beyond) the Moon, and he judged from their rising and setting that they had something in common with the stars.

Paracelsus insisted that comets were celestial messengers sent to foretell good or bad events, but he does not seem to have suggested how to discriminate between the different comets and the different events. It must be confessed that this idea has not yet died out, but subsists as regards both aspects. I believe I once saw it stated somewhere that Napoleon looked upon the great Comet of 1811 as presaging the success of his invasion of Russia, but in the event it was the other way about. Napoleon had previously regarded the great Comet of 1769 as his protecting *génie*, and as late as 1808 Messier published a book on it to uphold the idea.[c]

A story was told some 30 years ago in a well-known French periodical that at Moscow an unfavourable omen was drawn from the appearance of this comet. A conversation is related as having taken place between the abbess of a certain religious house and one of her nuns, to the following effect. One evening on their way to Church, the nun suddenly noticed the comet and uttered a cry of alarm, asking "what that star was." The abbess replied, "It is not a star: it is a comet." The nun rejoined, "But what is a comet? I never heard that word." The abbess then answered, "They are signs in the heavens, which God sends before misfortunes." The nun, who was the narrator of the story, thus comments on the occurrence: "Every night the comet blazed in the

[c] *La grande Comète qui apparut à la naissance de Napoléon le Grand.*

heavens, and we all asked ourselves, what misfortune does it bring?"[d]

Neither astronomy in general nor comets in particular owe much to the ancient Romans, for they did not trouble themselves much about astral phenomena, being more distinguished as warriors, lawyers, and bricklayers. Nevertheless they looked upon the Comet of B.C. 43 as a celestial chariot carrying away the soul of Julius Cæsar, who had been assassinated shortly before it made its appearance.

It is reported of the Emperor Vespasian, on the authority of Dion Cassius and Suetonius, that when nearing his end he heard some of his courtiers discussing in a low tone of voice the comet which was then visible. He seems to have taken a philosophical and very unusual view of the matter, for he is reported as having said: "This hairy star does not concern me: it menaces rather the King of the Parthians, for he is hairy, and I am bald."

VIRGIL compares a hero in his shining armour to a comet:—

> "Non secus ac liquida si quando nocte cometæ
> Sanguinei lugubre rubent." (*Æneid*, lib. x, ll. 272-3.)

Thus rendered by Davidson:—

"The golden boss of his buckler darts copious fires; just as when in a clear night the sanguine comets baleful glare."

In VIRGIL we find also another allusion to comets:—

> "Non alias cœlo ceciderunt plura sereno
> Fulgura, nec diri toties arsere cometæ."
> (*Georgica*, Bk. I, ll. 487-8.)

Thus rendered by the Rev. Canon Newbolt:—

> "At no other time did more thunderbolts fall in
> A clear sky, nor so often did dread comets blaze."

SUETONIUS, in his life of the Emperor Nero, has the following:—

"Stella crinita, quæ summis potestatibus exitium portendere vulgo putatur." (*Vita Neronis*, c. 36.)

[d] *Revue des Deux Mondes*, vol. cxvi, p. 200. July 1, 1873.

Thus rendered by A. Thomson :—

"A blazing star, which is vulgarly supposed to portend destruction to Kings and Princes, appeared above the horizon several nights successively." (Bohn's *Suetonius*, p. 366.)

Juvenal, the Satirist, evidently gives utterance to the commonly received opinion as to comets :—

> "Instantem regi Armenio Parthoque Cometem
> Prima videt. (*Satiræ*, vi, ll. 407–8.)

Thus rendered by L. Evans :—

> "She is the first to see the Comet that
> Menaces the Armenian and Parthian King."
> (Bohn's *Juvenal*, p. 53.)

Pliny's statement is comprehensive :—

"Cometas Græci vocant nostri crinitas : horrentes crine sanguineo et comarum modo in vertice hispidas." (*Hist. Nat.* Bk. II, c. 25.)

Thus rendered by P. Holland, Doctor in Physicke :—

"These blazing starres the Greekes call *cometas*, our Romanes *crinitas*, dreadful to be seene, with bloudie haires, and all over rough and shagged in the top like the bush of haire upon the head." (*The Historie of the World*, Fol. London, 1601, p. 15.)

Plutarch's account of comets might in modern language be described as "prosy". Here it is :—

"A Comet is one of those Stars which do not always appear, but after they have run through their determined course, they then rise, and are visible to us." [The writer then goes on to quote the opinions of a number of Greeks as to Comets.] (*Treatise on the Sentiments Nature Philosophers delighted in*, Lib. III, c. 2. Plutarch's *Morals*, vol. iii, p. 179, London, 1718.)

Claudius, who flourished early in the 5th century, remarked that "a comet was never seen in the heavens without implying disaster".

In an ancient Norman Chronicle there occurs a curious exposition of the Divine Right of William I. to invade England :—"How a star with 3 long tails appeared in the sky ; how the learned declared that stars only appeared when a kingdom wanted a king, and how the said star was called a Comette." The well-known writer William of Malmesbury, speaking in the year 1060, says : "Soon after [the death of Henry, King of France, by poison] a comet denoting, as they say, change in kingdoms—appeared, trailing its extended and

fiery train along the sky. Wherefore a certain monk of our monastery, by name Elmer, bowing down with terror at the sight of the brilliant star, wisely exclaimed, 'Thou art come! a matter of lamentation to many a mother art thou come; I have seen thee long since; but I now behold thee much more terrible, threatening to hurl destruction on this country.'" [e]

The superstitious dread in which comets were held in the Middle Ages is well exemplified in the case of what happened with respect to the Comet of 1456 (Halley's). There was a story long afloat that the Pope of the period, Calixtus III. excommunicated the comet, and took various steps of the necessary consequential character. This story has been proved to be a myth so far as regards its special point, and the whole incident must apparently be regarded as a remarkable instance of the way in which mountains grow out of mole-hills—to use a common simile. What happened appears to have been this. The comet was visible. The astrologers (I dare not call them astronomers) suggested that there would follow "a grievous pestilence, death, or some great calamity". At that time the Turks were making great headway in Central Europe. Inspired, no doubt, by these facts, Calixtus "ordered supplications that if evils were impending for the human race, the Almighty would turn them all upon the Turks, the enemies of the Christian name. He likewise ordered, to move God by continual entreaty, that notice should be given by the Church bells to all the Faithful, at midday, to aid by their prayers those engaged in battle with the Turk".

The foregoing sentence is translated from Platina's *Lives of the Popes*,[f] and it will be seen that there is no reference to any bull, or exorcism, or excommunication, or imprecation against the comet joined with the Turk. I suppose that what follows is history, but I give it under the shelter of Admiral Smyth's name. "By the way, while the *cometa monstriferus* was still in sight, Hunniades, the Pope's general, gained an

[e] *De Gestis Regum Angliæ*, lib. ii, cap. 225.

[f] *Vitæ Pontificum*, Venice, 1479.

DISCOVERY OF A COMET AT GREENWICH OBSERVATORY.

BY OUR UNTRUSTWORTHY ARTIST IN LONDON.

From 'Punch' for Dec. 5, 1906, *by the special permission of the Proprietors of 'Punch'.*

P. 208.

advantage over Mahomet, and compelled him to raise the siege of Belgrade; the remembrance of which Calixtus immortalised, by ordering the festival of the Transfiguration to be religiously observed throughout the Christian world. Thus was established the custom, which still exists in [Roman] Catholic countries, of ringing the bells at noon; and perhaps it was from this circumstance that the well-known cakes made of sliced nuts and honey, sold at the church-doors in Italy on Saints' days, are called *comete*."[g]

Leonard Digges, a writer of the Elizabethan epoch, says that "Cometes signifie corruption of the ayre. They are signes of earthquakes, of warres, of changying of Kyngdomes, great dearthe of corne, yea a common death of man and beast."[h]

John Gadbury, an astrological gentleman of the same epoch says that "experience is an eminent evidence that a comet like a sword portendeth war; and an hairy comet or a comet with a beard denoteth the death of Kings". He also gives a register of cometary announcements for upwards of 600 years, and adds in large Roman capitals: "as if God and Nature intended by comets to ring the knells of princes esteeming the bells in churches upon earth not sacred enough for such illustrious and eminent performances."

Close upon the heels of the two writers I have quoted comes the greatest of English writers, ancient or modern, Mr. William Shakespeare, whose works contain several noteworthy and very striking allusions to comets. Thus in *Julius Cæsar*:—

> "When beggars die, there are no comets seen,
> The Heavens themselves blaze forth the death of Princes."
>
> (Act II, Sc. 2.)

In *Henry VI.* we find the oft-quoted passage:—

> "Comets importing change of times and states
> Brandish your crystal tresses to the sky,
> And with them scourge the bad revolting stars
> That have consented unto Henry's death."
>
> (Part I, Act I, Sc. 1.)

[g] W. H. Smyth, *Cycle*, vol. i, p. 231. It has been suggested that a more rational derivation of the name of these cakes is *comedere*, the Latin for "to eat".

[h] *Prognostication Euerlastinge*, 2nd Ed., London, 1576, fol. 6.

There is a mixture of ideas here, for comets are regarded as prophetic of evil; and stars, not specially defined, are treated as co-operating in bringing about human misfortune.

There is another passage in *Henry VI.* which is even more dogmatic:—

> "Now shine it like a comet of revenge
> A prophet to the fall of all our foes."
> (Part I, Act III, Sc. 2.)

In *Hamlet* we find an evident allusion to comets though the word is not used:—

> "As Stars with trains of fire and dews of blood,
> Disasters in the Sun." (Act I, Sc. 1.)

In *Henry IV.* we have a great truism respecting comets:—

> "By being seldom seen, I could not stir,
> But, like a comet, I was wonder'd at."
> (Part I, Act III, Sc. 2.)

In the *Taming of the Shrew* we have a more general, but still sufficiently clear, allusion to the results which follow the appearance of a comet:—

> "Some Comet or unusual prodigy." (Act III, Sc. 2.)

Shakespeare lived at an epoch when, as we have seen in the quotations from Digges and Gadbury, Astronomy and Astrology were confused in men's minds, and discredit certainly brought on the former by the latter; but such ideas long remained current, and perhaps are by no means exploded even now in the 20th century. Certainly they were not non-existent in the 19th century. No wonder then that even in still earlier centuries we find alarmist passages in writers of repute.

Thus (to quote a few more) Spenser, describing a "goodly Lady", says:—

> "And her faire yellow locks behind her flew,
> Loosely disperst with puff of every blast:
> All as a blazing starre doth farre outcast
> His heavie beames, and flaming lockes dispredd,
> *At sight whereof the people stand aghast*;
> But the *sage Wisard telles*, as he has redd,
> *That it importunes death and dolefull dreryhedd.*"
> (*Faerie Queene*, Bk. III, Canto I, Stanza xvi.)

Tasso compares Argantes to a comet, and mentions divers ill-effects proceeding from comets :—

> "Qual con le *chiome sanguinose horrende*
> *Splender cometa* suol per l'aria adusta,
> *Che i regni muta, e i feri morbi adduce,*
> *Ai purpurei tiranni infausta luce.*"
> (*Gerusalemme Liberata*, Canto VII, Stanza lii.)

Rendered thus by Wiffen :—

> "And last, his wonted sabre by his side
> He girds, of purest steel, antique and rare,
> As with its bloody locks let loose in air,
> Horribly bright, *the Comet shows whose shine*
> *Plagues the parched World, whose looks the Nations scare,*
> *Before whose face States change, and Powers decline,*
> *To purple Tyrants all, an inauspicious sign.*"
> (*Jerusalem Delivered*, 5th ed., p. 160.)

Dante's reference to comets is on lines somewhat different from most of those quoted in this chapter—not so awe-inspiring :—

> "Così Beatrice : e quelle anime liete
> Si fêro spere sopra fissi poli,
> Fiammando forte *a guisa di comete.*"
> (*Paradiso*, Canto XXIV, l. 10.)

Thus rendered by Longfellow :—

> "Thus Beatrice : and those souls beatified
> Transformed themselves to spheres on steadfast poles,
> Flaming intensely *in the guise of Comets.*"
> (*The Divine Comedy*, Trans.—H. W. Longfellow.)

Milton's two allusions to comets are well-known :—

> "Satan stood
> Unterrified, and like a Comet burn'd
> That fires the length of Ophiuchus huge
> In th' Artick sky, and from its horrid hair
> Shakes pestilence and war." (*Paradise Lost*, Bk. II, l. 706.)

Professor H. H. Turner thinks that Milton "almost certainly" was referring to a particular comet, namely, the Comet of 1618, which Evelyn (in his *Diary*) held responsible for the great "Thirty Years' War". This comet did indeed appear in Ophiuchus, but Milton was only 10 years old at the time. Turner's argument is that, as the said comet was a specially magnificent one with a tail 104° long, "the impres-

sion made on the mind even of a boy of 10 may well have lasted until he wrote the above lines as a man of 50. It has been usual to regard the particular reference, if any, as being to the Comets of 1664 and 1665 of which M. Auzout predicted the movements, the former of which was believed to have led to war with the Dutch, and the latter to the Plague of London. But Milton never saw these comets, being already blind: and unless the lines were added in revision, they were probably written before 1664. Moreover, neither of these comets, nor any intermediate comets (of which there were no striking examples), was in Ophiuchus; and the explanation offered of the use of this name because it was 'fine-sounding' is scarcely satisfactory. It is true that Ophiuchus is not 'in th' Arctic sky', being by no means a northern constellation: but these words probably refer rather to the attitude of the poet himself, since Milton continually posed as a classical poet writing from Italy; and may in this case have desired to make it clear that the comet had been seen from England".[1]

Milton has another reference to a comet further on in the same poem:—

"High in front advanc'd
The brandish'd sword of God before them blaz'd
Fierce as a Comet: which with Torrid heat,
And Vapours as the Libyan air adust,
Began to parch that Temperate clime."
(*Paradise Lost*, Bk. XII, l. 632.)

This last passage from Milton seems evidently plagiarised from Tasso, as quoted above, but for the comparison of the sword of God to a comet Dunster refers to DU BARTAS'S description of the flaming sword placed at the entrance of the Garden of Eden after the expulsion of our first parents. Todd thus rendered the passage:—

"For the Almighty set before the door
Of th' holy park a Seraphin that bore
A waving sword, whose body shined bright
Like flaming comet in the midst of night."

[1] "*Lecture on Halley's Comet to the British Association*, 1898," p. 6. The suggestion in the last sentence of this extract, which Turner says he owes to a friend, seems to me a case of drawing on one's imagination for one's facts!

POPE, who dealt with many topics, did not forget comets :—

> "Could he, *whose rules the rapid comet bind*
> Describe or fix one movement of his mind ?
> Who saw its fires here rise and there descend
> Explain his own beginning or his end."
>
> (*Essay on Man*, Epistle II, l. 35.)

The "he" in the foregoing challenge is Sir I. Newton.

In another of his works, desirous of satirising the notorious Duke of Wharton, Pope sarcastically says :—

> "*Comets are regular*, and Wharton plain."
>
> (*Moral Essays*, Epist. i, l. 209.)

If contemporary records are to be trusted, the Duke resembled the average comet by being very irregular in ways which defy description in these pages.

The next extract is from THOMSON :—

> "Amid the radiant orbs
> That more than deck, that animate the sky,
> The life-infusing suns of other worlds;
> Lo! from the dread immensity of space,
> Returning, with accelerated course,
> *The rushing Comet* to the Sun descends :
> And, as he shrinks below the shading earth,
> *With awful train projected o'er the heavens,*
> *The guilty nations tremble.*" (*Seasons*, Summer.)

I have somewhere seen it stated that Lord BYRON wrote of "The Comet of a Season", but I have been unable to find the reference. In his "Prayer to Nature" he evidently has a comet in his mind when, addressing the Almighty, he says :—

> "Thou who canst guide the wandering star
> Through trackless realms of æther's space ;
> Who calm'st the elemental war,
> Whose hand from Pole to Pole I trace."

As might be expected, we find something about comets in YOUNG :—

> "Hast thou ne'er seen the *Comet's flaming flight?*
> *Th' illustrious stranger passing, terror sheds*
> *On gazing Nations*, from his fiery train
> Of length enormous, takes his ample round

Thro' depths of ether; coasts unnumber'd Worlds,
Of more than solar glory; doubles wide
Heav'n's mighty cape; and then revisits earth,
From the long travel of a thousand years."
(*Night Thoughts*, No. iv.)

The quotation given on the title-page of this volume is the first stanza of a poem published in the *Illustrated London News* of March 25, 1843, concerning the great Comet of 1843. Some other stanzas deserve reproduction :—

"Thou comest whence no mortal seer can know—
Thou goest whither nothing human dreams—
Thy mission, tho' so bright,
Is speculation's gloom!
We can but gaze upon the starry dust
Thy lightening wheels upturn

"Along Heav'n's road, and call thee charioteer,
Or names which prove that man cannot baptize
Such giant births as thou
With aught descriptive term!
Comet, or fiery star, or feeding light
To myriad viewless suns.

"Roll on, thou child of wedded time and space,
Eccentric offspring of Eternal Pow'r,—
Be thy portent to us
Or good or ill, the same—
We'll pay thee symbol worship for thy cause,
And in submission bow.

"Com'st thou in anger, we will not repine—
Com'st thou in harmless beauty, we'll adore,
And through thee bless the ONE
Who by His simple Word
Can call creations like to thine from nought
And end them all again!

"Beautiful—lustrous as the heav'ns can be
On vernal nights with their commission'd stars,
How much more do they seem,
When unaccustom'd lights,
Like thine shoot forth from out the sapphire throne
Whereon the GREAT ONE sits!" "W."

Another poet took up the running in a subsequent number of the same newspaper (April 22, 1843):—

TO THE COMET.

"Thereby hangs a tail."—Shakespeare.

"Lone wanderer of the trackless sky!
Companionless! Say dost thou fly
Along thy solitary path,
A flaming messenger of wrath—
Warning with thy portentous train
Of earthquake, plague, and battle-plain?
Some say that thou dost never fail
To bring some mischief in thy tail:
For ignorance doth ever see,
Wrapped in its vain credulity,
Coupled some dire mishap with thee." W. Lattey.

That the terror inspired by comets had by no means died out in the 19th century is well shown by the following extract from an American newspaper published in the form of a letter from Atlanta, Georgia, on the occasion of the expected appulse of Biela's Comet in November 1872:—"The fear which took possession of many citizens has not yet abated. The general expectation hereabouts was that the comet would be heard from on Saturday night. As one result, the confessionals of the two [Roman] Catholic churches here were crowded yesterday evening. As the night advanced there were many who insisted that they could detect a change in the atmosphere. The air, they said, was stifling. It was wonderful to see how many persons gathered from different sections of the city around the newspaper offices with substantially the same statement. As a consequence, many families of the better class kept watch all night, in order that if the worst came they might be awake to meet it. The orgies around the coloured churches would be laughable, were it not for the seriousness with which the worshippers take the matter. To-night (Saturday) they are all full, and sermons suited to the terrible occasion are being delivered."

Let us hope that the late Earl of Malmesbury did not exactly mean what he said when he wrote in his Diary (Sept. 16, 1858) respecting Donati's Comet of 1858:—"The largest comet I ever saw became visible with a very broad

tail spread perpendicularly over the sky, the weather being very hot. *Every one now believes in war.*"[k]

Of the influences ascribed to comets in the popular mind one which has survived quite to the present day is that comets cause an abnormal developement of heat on the Earth. When there has happened to be visible a comet of sufficient importance or brilliancy to get into the newspapers, and the season of the year has been the summer, or early autumn, and the weather has been very sunny and hot, I have often been asked in solemn tones (especially by ladies) whether the comet was the cause of the heat; the question being put in the form called by a lawyer a "leading question", one to which an affirmative answer is expected.

Lord Malmesbury, in the work just quoted, alludes casually to this popular idea. Under the date of 1857, June 25, he says:—"We are suffering under an extraordinary heat. People are really getting alarmed, for if it is occasioned by the comet, which is not yet visible, what must we expect when it reaches our Globe!" It does not appear what comet is here referred to, but presumably it is that of 1556, whose return was expected somewhere about 1858 or 1860.[l]

The French astronomer Arago, more than 70 years ago, complained that questions of the same type were raised in France, and he wrote a somewhat satirical article dealing with the subject,[m] in which he alluded to the scarcity of the meanest knowledge of scientific facts amongst the middle ranks of society. He condescended, however, to gather up some statistical facts by way of showing the futility of the suggestion. His labours were taken advantage of in England in an article attributed to the late Professor De Morgan.[n] Allusion is made therein to the supposition that the successful vintage of 1811 was due, as already mentioned, to the great Comet of 1811; and that the excessive heat of August and

[k] *Memoirs of an Ex-Minister*, vol. ii, p. 135.

[l] See p. 100 (*ante*).

[m] *Annuaire du Bureau des Longitudes*, 1832, see p. 238. An English translation in the form of a small book appeared in 1833.

[n] *Companion to the Almanac*, 1833, p. 1.

September 1832 was occasioned by the approach of Biela's Comet. De Morgan pertinently remarks that, "With a burning Sun overhead we have heard those who might have known better accusing the comet in the manner aforesaid."

Arago's article contains a statement of the mean temperature of every year from 1803 to 1831 inclusive; and side by side is placed the number of comets visible in each year. Inspection of the table conclusively shows that there is no connection between the two things. Thus 1806 and 1811 were both hot years; the first, however, hotter than the second, though the first had only one comet of no note, whilst the second had two comets, one of which was of remarkable brilliancy. Again, 1826 with its 5 comets was not nearly so warm as 1831 with its one comet. That hot years have in general more comets than cold ones is very true, and for the simple reason that hot years generally giving clear skies are more favourable for the discovery of comets than cold years, which so often mean cloudy skies. Nor must it be forgotten that the greater number of comets are not visible to the naked eye. Thus all the years between 1803 and 1831 inclusive, the temperature of which exceeded the average, mustered 29 comets between them ; and the remaining or cold years only 15. It is therefore more reasonable to say, not that the comets brought the heat, but that the heat brought the comets. I have not thought it worth while to attempt to bring these figures up to date by comparing the temperatures of the years 1832 to 1909 with the comets of those 78 years ; but that would be a suitable occupation for anybody who is fond of shooting the air. I cannot doubt what the result of such a research would be.

French writers on scientific subjects are very fond of interweaving with their facts a large mixture of fancies and romance. Jules Verne and F. A. Pouchet are types of what I mean. No wonder, therefore, that Astronomy is not exempt from that sort of thing. Accordingly we find that Guillemin, who with Flammarion may be taken to represent in French literature the department of Astronomy, is not behind his fellow-countrymen in sensational writing. In his book on

comets he propounds a variety of questions, many of which are altogether outside practical politics. I select one as a sample of the rest. "Are comets habitable?" I should suppose that no Englishman who had read half-a-dozen pages in any English book on comets would have paused for a moment even to have discussed such a question, and though it must be admitted that Guillemin answers his question in the negative, he nevertheless wastes several pages over it, citing De Fontenelle[o] and Lambert[p] in particular. The form of his question he evidently borrows from Lambert, who seriously thought to advance reasons to permit us to believe that comets, more numerous than the planets in the Solar System, are habitable celestial bodies. I am sorry to have to add that one erratic Englishman was found in 1772 to take up the same line of writing.[q]

During the visibility of Donati's Comet in 1858, I remember that a correspondence took place in the newspapers as to whether comets were mentioned, or in any sort of incidental way referred to, in the Bible. The following passages were adduced in support of an affirmative answer to this question:—

(1) In *Leviticus* xvii. 7, it is said, "They shall no more offer their sacrifices unto *Seirim*" or "*Shoirim*", which is rendered in the Authorized Version "devils", and in other versions "goats". The Jewish writer, Maimonides, states that the Sabian astrologers worshipped these "Seirim", which seems to confirm the idea that they were celestial bodies of some sort.

(2) In *Isaiah* xiv. 12, we find, "How art thou fallen from Heaven, O Lucifer, son of the morning! How art thou cut down to the ground which didst weaken the nations!" In this passage a certain Hillel is said to have fallen from Heaven, but it is unknown what Hillel means. Some interpreters derive the word from Hebrew verbs signifying to shine, to glory, to boast, to agitate, to howl, &c. A writer minded to

[o] *Entretiens sur La Pluralité des Mondes. Œuvres*, vol. ii, Paris, 1766. An English translation by J. Jacque was published in 1800.

[p] Lambert explicitly asserts that comets and planets alike are inhabited. "Les comètes et les planètes sont également habitées." *Système du Monde*, 2nd ed., Paris, 1784, p. 45.

[q] Andrew Oliver: *Essay upon Comets.*

obtain a far-fetched or expansive view of words suggested that Hillel indicated a comet, because comets answer to the ideas of brightness, swift motion, and calamity.

(3) In the *General Epistle of St. Jude,* verse 13, certain impious impostors are compared to "wandering stars to whom is reserved the blackness of darkness for ever [for an aeon = age]." The term "wandering stars" has been thought to refer to comets.[r]

(4) In the *Revelation of St. John the Divine,* xii. 3 :—"There appeared another wonder in Heaven ; and behold a great red dragon . . . and his tail drew the third part of the stars of Heaven". Satan is here likened, it is supposed, to a comet, because a comet resembles a dragon (or serpent) in form, and its tail frequently may be said to compass, or to seem to grip stars.

These ideas are given for what they are worth, and on this point the reader must exercise his own judgement, especially bearing in mind Maunder's words in his excellent and most interesting book :—"We cannot expect to find in Scripture definite and precise descriptions that we can recognize as those of comets. At the most we may find some expressions, some descriptions, that to us may seem appropriate to the forms and appearances of these objects, and we may therefore infer that the appearance of a comet may have suggested these descriptions or expressions".[s]

It may be added that Maunder leans to the suggestion made by several writers that when Jerusalem was wasted by a pestilence and David offered up a sacrifice of intercession at the threshing-floor of Ornan, the Jebusite, the king may have seen in the scymitar-like tail of a comet (such as that of the comet of 1882 [t]), what was to be regarded as God's "minister, a flaming fire".[u]

To quote the actual words of the sacred writer will make the point more clear :—"And David lifted up his eyes, and

[r] See Alford's *New Test. for English Readers, in loco.*

[s] E. W. Maunder: *The Astronomy of the Bible,* p. 105.

[t] See pp. 153–4 (*ante*).

[u] Psalm civ. 4.

saw the angel [messenger] of the Lord stand between the Earth and the Heaven, having a drawn sword in his hand stretched out over Jerusalem".[x] It will not be forgotten that Josephus used almost the same language many centuries later under circumstances not altogether dissimilar.[y]

The following extract from the quarto edition of Littré's French Dictionary (*sub. voc., Comète*) will I think be new to English Readers and may appropriately end this chapter :—

"Comet: a card game played with 2 packs of cards from which the aces have been removed. One of the two packs is printed in black ink, and the other in red. On one of the cards the figure of a comet appears; or, as a substitute, the nine of diamonds in the black pack, and the nine of clubs in the red pack are used." "It is true that she made more progress in the game of comet and in backgammon than in spelling, and she plays the comet card more easily than she writes a letter."

The last sentence is given as a quotation from Voltaire describing the educational developement of a certain Mademoiselle Corneille.[z]

It may be added (though I have been unable to trace the authorities) that it has been said that the origin of the phrase the "Curse of Scotland", applied to the Nine of Diamonds, was that the "Game of Comet" was introduced into Scotland by French members of the retinue of Mary, Queen of Scots, and became so popular with the upper classes as to lead to an immense developement of gambling, the game acquiring its Scotch repute from the name of its Trump Card.

[x] 1 Chron. xxi. 16. [y] See p. 123 (*ante*).
[z] *Lettres à M. le Comte D'Argental,* Jan. 23, 1763.

CHAPTER XV.

COMETARY STATISTICS.

Statistics not generally appreciated.—Difficulty of being precise in dealing with Cometary Statistics. — Nuclei. — Comæ. — Tails. — Orbits. — Number of Comets recorded and calculated. — Duration of visibility. — Periodical Comets and their returns.—Direction of Motion of Periodical Comets.—Perihelia.—Ascending Nodes.—Inclinations of Orbits.—Perihelion Distances.—Direction of Motion.

STATISTICS are usually supposed to be distasteful to the general reader, and I shall not here submit any very elaborate ones; and those which are presented may be passed over altogether if the reader likes, for they are not essential to a study of the subject of comets from a descriptive or observational point of view. And, indeed, there is another reason why they may be pardonably neglected: for if the truth must be told, many of those which appear in this chapter are in a certain sense untrustworthy. A moment's reflection will make it plain why such should be the case. Comets have, at the best, very ill-defined boundaries; and as a large telescope will reveal a greater spread of cometary material than a small one, it follows, as a matter of course, that dimensions measured in a small telescope may differ very much indeed from those obtained by means of a large telescope. Discrepancies are bound, therefore, to occur in the measurements arrived at by different observers using, even on the same day, telescopes of different optical power.

The same remark applies to the differences which exist between the sensitiveness of the eyes of different observers, a fact which very often becomes very pronounced, when it is

a question of estimating the length of a comet's tail. One observer may see, and perhaps even instrumentally measure, a tail as being 5° long, when on the same night, in perhaps a different and better atmosphere, and possessed of a more sensitive eye, another observer will have no difficulty in tracing a tail through 8° or even 10°. With these cautions and reservations the statistics of measurements which follow are offered for what they are worth.

The following are the real diameters in English miles of the *nuclei* of some of the comets which have been measured [a] during the last 100 years or so.

Examples of a Large Nucleus.	Miles.	*Examples of a Small Nucleus.*	Miles.
The Comet of 1845 (iii.) ...	8000	The Comet of 1798 (i.) ...	28
Donati's Comet, 1858 ...	5600	The Comet of 1806	30
The Comet of 1815... ...	5300	The Comet of 1798 (ii.) ...	125
The Comet of 1825 (iv.) ...	5100	The Comet of 1811 (i.) ...	428

The dimensions of the *comæ* or heads of comets also vary very greatly. Thus:—

Examples of a Large Coma.	Miles.	*Examples of a Small Coma.*	Miles.
The Comet of 1811 (i.)	1,125,000	The Comet of 1847 (v.) ...	18,000
Halley's Comet, 1835...	357,000	The Comet of 1847 (i.) ...	25,500
Encke's Comet, 1828 ...	312,000	The Comet of 1849 (ii.)...	51,000

The real dimensions of a comet vary very much at different periods of the same apparition, for there is no doubt that many of these bodies *contract* as they approach the Sun and

[a] All the dimensions given in miles in this chapter depend on the old value (8·57″) of the Sun's parallax. They need to be augmented by about $\frac{1}{30}$th to harmonise them with what is now regarded as the probable value (8·8″) of the Sun's parallax; but for reasons which will be readily inferred from what has been stated at the commencement of this chapter, it has been deemed unnecessary to transform the figures, as it would be affectation to present them with such an appearance of exactitude, as measures ending in figures, and not cyphers would imply.

expand again as they recede from it; a fact first noticed by Kepler in the case of the Great Comet of 1618.

The following measurements of Encke's Comet in 1838, when approaching the Sun, will illustrate this:—

Date.	Diameter.	Distance from ⊙.
1838.	Miles.	
Oct. 9	281,000	1·42
„ 25	120,500	1·19
Nov. 6	79,000	1·00
„ 13	74,000	0·88
„ 16	63,000	0·83
„ 20	55,500	0·76
„ 23	38,500	0·71
„ 24	30,000	0·69
Dec. 12	6,600	0·39
„ 14	5,400	0·36
„ 16	4,250	0·35
„ 17	3,000	0·34

We have already considered the interesting questions, "Do periodical comets diminish in brilliancy from time to time at successive apparitions?" and, "Do they waste away?"

It seems certain that both these questions must be answered in the affirmative; and I have already mentioned[b] Halley's Comet as probably proving this point. Very likely there is some significance in the fact that none of the now considerable number of short-period comets exhibit more than what may be called apologies for tails, and some of them not even the semblance of a tail.

THE TAILS OF COMETS.

The tails of comets, more especially of those splendid ones which now and again become visible to the naked eye, are often of stupendous length, as the following Table will show:—

[b] See p. 5 (*ante*).

Name of Comet.	Length in Arc.	Length in Miles.
	°	
The Comet of 1744	24	19,000,000
The Comet of 1860 (iii.)	15	22,000,000
The Comet of 1861 (ii.)	105	24,000,000
The Comet of 1769	97	40,000,000
The Comet of 1858 (vi.)	50	42,000,000
The Great Comet of 1618	104	50,000,000
The Comet of 1680	60	100,000,000
The Comet of 1811 (i.)	25	100,000,000
The Comet of 1811 (ii.)	37	130,000,000
The Comet of 1843 (i.)	65	200,000,000

DIMENSIONS OF ORBITS.

We all know that in speaking of the dimensions of the orbits of the planets we are brought face to face with stupendous figures which the mind can with difficulty grasp; but such figures fade into insignificance when we come to consider the distances to which some of the periodical comets recede when at their greatest, or aphelion, distance from the Sun; though perihelion distances may in many cases be grasped without difficulty. The following figures will illustrate these 2 points:—

1. *Perihelion Distances.*

Greatest known.	Miles.	*Least* known.	Miles.
The Comet of 1729 ...	383,800,000	The Comet of 1843 (i.) ...	538,000

2. *Aphelion Distances.*

Greatest known.	Miles.	*Least* known.	Miles.
The Comet of 1844 (ii.)	406,130,000,000	The Comet of Encke ...	388,550,000

From the earliest period up to the present time the number of comets of which we have any trustworthy record may be put at something like 1200; but as it is only within the last 150 years that optical assistance has been made generally available in systematic searching for them, and only within the last 20 years that systematic search has been carried out on a large scale, it can scarcely be doubted that the real

number of the comets which have visited our system during what is called the "Historic Period" cannot be less than several thousands, especially as our statistics until quite recently have not embraced the Southern hemisphere. Comets are often visible in the Southern hemisphere which escape the notice altogether of the comet-hunters of Europe, of North America, and of the Northern hemisphere generally.

TABLE OF NUMBER OF COMETS RECORDED.

Period.	Comets Observed.	Orbits Calculated.	Comets Identified.
Before A.D.	81	4	1
Century 0—100	22	1	1
101—200	22	2	1
201—300	39	3	2
301—400	22	0	1
401—500	19	1	1
501—600	26	4	1
601—700	33	0	2
701—800	17	2	1
801—900	41	1	0
901—1000	30	2	3
1001—1100	38	4	2
1101—1200	31	0	1
1201—1300	30	3	3
1301—1400	34	7	3
1401—1500	45	12	1
1501—1600	40	13	4
1601—1700	35	20	5
1701—1800	73	64	8
1801—1900	335	313	86
1901—1909 (Jan. 1) ...	39	36	8
	1052	492[c]	135

[c] This number is greater by 3 than the highest numbered orbit in the catalogue because three additional orbits are given which had to be numbered *bis*, or rather *a*.

VISIBILITY OF COMETS.

Comets remain visible for periods varying from a few days to more than a year, but the most usual time is 2, 3, or 4 months. Much depends on the apparent position of the comet with respect to the Earth and the Sun, and much on its own intrinsic lustre. The statement just made of comets being visible only for periods of a limited number of months is not so generally true now as it was 20 years ago, for the duration of their visibility is now affected very often by 2 circumstances of quite recent origin—the employment of the very large American telescopes of 30 or 40 inches aperture, and the use of photography. It is to the operation of these 2 causes that the long periods of time disclosed in the following table are due.

Name of Comet.	Duration of Visibility.
The Comet of 1905 (iv.)	$3\frac{1}{2}$ years
The Comet of 1889 (i.)	2 years
The Comet of 1890 (ii.)	22 months
The Comet of 1811 (i.)	17 months
The Comet of 1904 (i.)	12 months
The Comet of 1825 (iv.)	12 months
The Comet of 1861 (ii.)	12 months
The Comet of 1907 (iv.)	10 months
The Comet of 1835 (iii.) (Halley's)	$9\frac{1}{2}$ months
The Comet of 1847 (iv.)	$9\frac{1}{2}$ months

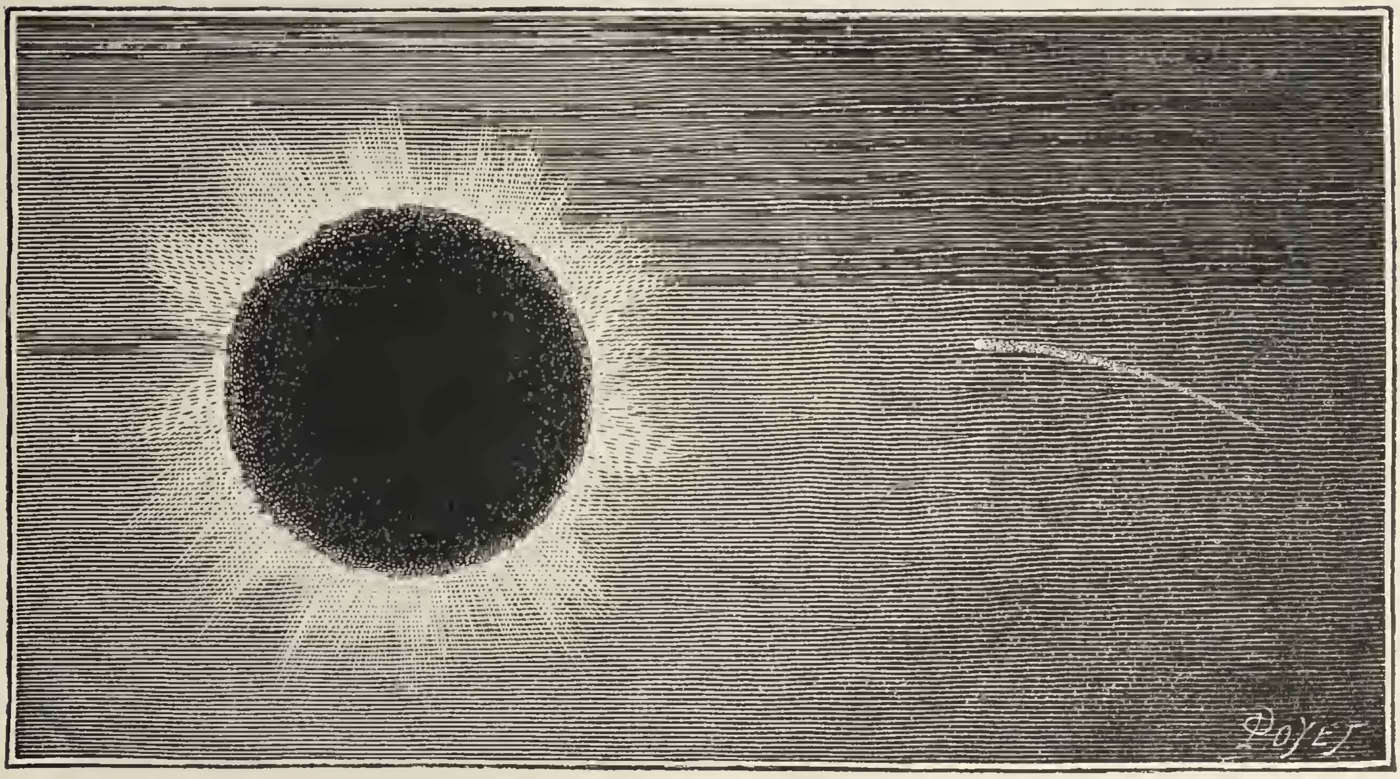
There are a few comets on record, even during the modern telescopic period, which have only been seen on one or two occasions, unfavourable weather, or unfavourable position in the heavens, having prevented a more extended observation of them. Fig. 106 is a case in point. It represents a comet seen during the totality of the Eclipse of the Sun of May 17, 1882, which comet was never seen again, and whose history and circumstances will probably remain for ever undisclosed.

And again, during the Eclipse of the Sun of April 16, 1893, a comet was seen. But long before this, Seneca, quoting Posidonius, records an eclipse comet. (*Quæst. Nat.*, vii. 20.)

It not unfrequently happens that a comet is only discovered after its perihelion passage, when it will be receding from the the Sun, and perhaps also from the Earth. As under such circumstances its brightness will be day by day diminishing, its visibility may only extend to a few days, or a few weeks.

From an examination of a complete catalogue of calculated

Fig. 106.



ECLIPSE OF THE SUN OF MAY 17, 1882, SHOWING AN UNKNOWN COMET. (*Ranyard.*)

comets[d] we may obtain certain results which will here be analysed.

It appears that 492 comet apparitions have been subjected to mathematical investigation, viz.:—

Known periodical comets	30
Subsequent returns	108
Elliptic comets not yet verified, and parabolic comets	341
Hyberbolic comets	13
	492

[d] See the Catalogue in the Appendix (*post*), read as a continuation of Catalogue I. in my *Handbook of Astronomy*, 4th ed., vol. i, p. 511.

Of known periodical comets, we have the following, as the number of the apparitions of each :—

30	of Encke's.
17	of Halley's.
8	of Faye's.
7	of Winnecke's.
6	of Biela's.[e]
6	of D'Arrest's.
5	of Brorsen's.
5	of Tuttle's.
5	of Tempel's IInd.
4	of Tempel's IIIrd-Swift's.
3	of Tempel's Ist.
3	of Brooks's IInd.
3	of Finlay's.
3	of Holmes's.
3	of Wolf's.
3 ?	of Di Vico's.

Also 2 of each of the following :—

961 : 1097 (i.) : 1231 : 1264 : 1362 (i.) : 1532 : 1596 : 1699 (i.) : 1790 (iii.) 1810 : 1812 : 1815 : 1818 (i.).

Elliptic orbits have been assigned in the Catalogue to various comets, of which however no 2nd returns have as yet taken place.

Elliptic orbits have been assigned by some computers to certain other comets; of which it must be said that the probability is not sufficiently great at present to warrant their being included in a list of undoubted elliptic comets.

The question, "How many comets are known to be moving in elliptic orbits" is one rather difficult to answer. If in any given case a period of less than 100 years can be assigned to a comet it will generally be found that all the different computers who have investigated its orbit will be agreed within a few years. But it is very different where hundreds of years are in question. An ellipse implying that length is so elongated: in other words, is so nearly parabolic *so far as available observations go* that one computer will pronounce

[e] For reasons very fully set forth in Chapter I. (*ante*), it is doubtful whether this comet ought any longer to be included in a list of known periodical comets.

for an ellipse when another equally competent and with equally good materials (*i. e.* observations) to go upon, will stand out for a parabola. I have often found it very difficult in compiling catalogues and statistics of comets to hold the balance between rival computers, and in no case do I wish that any decision to include or exclude an elliptic orbit as against a parabolic orbit or one ellipse as against another is to be deemed above challenge.

The orbits of the following comets are hyperbolic:—

1729 : 1771 : 1774 : 1840 (i.) : 1843 (ii.) : 1853 (iii.) : 1866 (i.) : 1883 (i.) : 1890 (ii.) : 1896 (ii.) : 1897 (i.) : 1898 (vii.) : 1899 (i.) : 1900 (ii.).

Hyperbolic orbits have been assigned by some computers to the following comets: but the probability is not sufficiently great to warrant their being definitely given as such:—

1723 : 1773 : 1779 : 1818 (iii.) : 1826 (ii.) : 1830 (i.) : 1843 (i.) : 1844 (iii.) : 1845 (i.) : 1845 (ii.) : 1849 (iii.) : 1852 (ii.) : 1863 (vi.) : 1886 (ii.).

The following are some of those comets which have been supposed to be identical:—

1894 (iv.)	with	1844 (i.), and 1678.
1895 (ii.)	—	1770 (i.) (Lexell's).
1881 (v.)	—	1855 (ii.).
1880 (i.)	—	1843 (i.).
1880 (iii.)	—	1569, 1506, 1444, or 1382.
1873 (vii.)	—	1818 (i.).
1871 (ii.)	—	1827 (i.).
1863 (v.)	—	1490.
1860 (i.)	—	1845 (ii.), 1785 (i.), and 1351.
1858 (vi.)	—	146 B.C.
1858 (iv.)	—	1799 (ii.).
1857 (v.)	—	1825 (i.), and 1790 (iii.).
1854 (iv.)	—	1558.
1854 (ii.)	—	1799 (ii.).
1853 (iv.)	—	1582 (ii.).
1853 (i.)	—	1664.
1852 (ii.)	—	1819 (ii.).
1844 (i.)	—	1678.
1843 (i.)	—	1668 and many others.
1840 (iv.)	—	1490.
1827 (iii.)	—	1780 (i.).
1819 (iv.)	—	1743 (i.).
1819 (iii.)	—	1766 (ii.).
1661	—	1532.

The *Perihelion* points are not distributed at all evenly in longitude all round the Sun, for more than 60 per cent. are concentrated within 45° of longitude on either side of what has been called "the Sun's Way", *i. e.* the line in space along which the Sun with its attendant planets is supposed to be travelling. I do not exactly know who was the first to point out this concentration, but Denning has reminded me in a private letter that "the circumstance is so marked that there is certainly some significance in it".

The *Ascending Nodes* are distributed all round the ecliptic, with however a decided tendency to concentrate around two points having respectively the longitudes of about 80° and 270°.

The *Inclinations* of the orbits of comets vary from 0° to 90°: in other words, comets may be found moving almost in the ecliptic, or at any angle between that and a perpendicular to the ecliptic. When a new comet is found to have a small inclination (anything under 15°) it is not unlikely that the orbit is an ellipse and the comet a periodical one.

The *Perihelion Distances* of comets vary greatly. 11 comets have a perihelion distance less than 5 millions of miles: about 64 per cent. of all that have been calculated lie within the Earth's orbit; about 30 per cent. lie outside, but within twice the Earth's distance from the Sun; and 16 comets have been observed with a perihelion distance exceeding that limit. A single one, the Comet of 1729, had a perihelion distance exceeding 4 radii of the Earth's orbit—as great a distance as the remoter asteroids. Young well remarks:—"it must have been an enormous comet to be visible at such a distance."

The figures which have yielded the foregoing results are the following:—

Perihelia within the Earth's orbit	248
Perihelia outside the Earth's orbit within 2 Radii	117
Perihelia outside the Earth's orbit more than 2 Radii but less than 4	15
Perihelion beyond 4 Radii of the Earth's orbit	1
	381

The *Direction of Motion* of a comet is a matter of some interest. With 2 exceptions all the periodical comets of less

periods than 80 years move in the order of the signs of the Zodiac, or "direct" (+). The 2 exceptions are Halley's Comet and the "Comet of the Leonid or November Meteors". The long-period comets and the parabolic and hyperbolic comets show a slight preponderance for Retrograde Motion (−), or motion contrary to the order of the signs of the Zodiac.

As an incidental matter of statistics, A. S. Herschel remarked on the rarity of the near approach of comets to the Earth's orbit. He found that of 80 new comets observed between 1872 and 1892, only 2 came at all near to the orbit of the Earth, namely the Comets of 1881 (v.) and 1886 (vii.). These came within about 3,000,000, and 4,600,000 miles respectively of the Earth's orbit, but these distances were not sufficiently small for a Meteor shower to be visible as the result of the appulse.[f]

[f] *Month. Not. R.A.S*, vol. lvii, p. 280. Feb. 1897.

APPENDIX I.

A CATALOGUE OF RECENT COMETS.

1888–1908.

The following Catalogue comprises all the comets which have appeared, and whose orbits have been calculated, between 1888 and 1908 inclusive, and is a continuation in the same form of the Catalogue No. I. which appears in my *Handbook of Astronomy*, 4th edition, vol. i; and the progressive numbers are carried on from that Catalogue, but with the last imperfect page repeated. The arrangement of the columns is the same except that the old Element, which used to be called the "Longitude of the Perihelion", and was represented by the Greek letter π, is replaced, to meet modern usage, by the "Argument of Perihelion", represented by the Greek letter ω. This is recommended for adoption by W. C. Winlock as having "a simpler geometrical signification than the longitude of the Perihelion π, and is now much more commonly used by Computers". For further remarks on this matter reference may be made to Chapter XI (*ante*).

A very elaborate statistical catalogue of all the comets calculated up to 1895 will be found in the *Publications of the Astronomical Society of the Pacific*, vol. viii, p. 141, June 1896. The compiler, W. C. Winlock, after giving the catalogue proper, has put all his comets into classes according to the different Elements, the members of each class being arranged in order from zero to the maximum figure, whatever it may be, degrees of arc, radii of the Earth's orbit, or eccentricity, &c.

Another catalogue of some value compiled by J. G. Galle, appears in *Ast. Nach.*, vol. cxii, Nos. 2665–6, June 5, 1885. It comprises all comets from 1860 to date, and improved orbits of many older comets, but its matter is embodied in Galle's book published in 1894 (see Appendix III, *post*).

In the appendix to the *Index to vols. xxx to lii of the Monthly Notices R. A. S.* there is a very useful table compiled by A. C. D. Crommelin of Reference Letters, Year-numbers, Dates of Discovery, Perihelion Passages, and Periods (if any) of comets discovered between 1869 and 1894.

Several of the books on comets, mentioned under the head of "The Literature of Comets" in Appendix III, contain catalogues of comets, some of them very exhaustive, but unfortunately they do not for the most part come down very near to the present epoch.

No.	No.	Year.	PP.			ω		☊		*i*		*q*
				d.	h.	°	′	°	′	°	′	
388	307	1888 iii.	July	31	4	59	12	101	29	74	11	0 9022
389	(171)	— iv.	Aug.	19	22	201	13	209	35	11	19	1·7381
390	308	— v.	Sept.	13	0	291	0	137	34	56	24	1·5321
391	309	1889 i.	Jan.	31	6	340	28	357	24	166	22	1·8151
392	310	— ii.	June	10	18	236	5	310	42	163	50	2·2553
393	311	— iii.	June	20	18	60	8	270	58	31	12	1·1024
394	312	— iv.	July	19	7	345	51	286	9	65	58	1·0397
395	313	— v.	Sept.	30	8	343	35	17	59	6	4	1·9499
396	314	— vi.	Nov.	29	13	69	39	330	36	10	14	1·3537
397	315	1890 i.	Jan.	26	12	199	54	8	23	56	44	2·6972
398	316	— ii.	June	1	13	68	56	320	20	120	33	1·9075
399	317	— iii.	July	8	13	85	39	14	18	63	20	0·7641
400	318	— iv.	Aug.	7	3	331	21	85	22	154	19	2·0481
401	(195)	— v.	Sept.	17	12	172	58	146	16	15	42	1·3240
402	319	— vi.	Sept.	24	12	163	2	100	7	98	56	1·2602
403	320	— vii.	Oct.	26	3	13	5	45	8	12	51	1·8179
404	321	1891 i.	April	27	13	178	55	193	55	120	31	0·3970
405	(290)	— ii.	Sept.	3	10	172	48	206	22	25	14	1·5928
406	(105)	— iii.	Oct.	17	23	183	57	334	41	12	54	0 3404
407	322	— iv.	Nov.	12	23	268	37	217	40	77	44	0·9763
408	(247)	— v.	Nov.	14	23	106	43	296	31	5	23	1·0866
409	323	1892 i.	April	6	16	24	31	240	54	38	42	1 0268
410	324	— ii.	May	10	0	128	40	253	17	89	44	1·9751
411	325	— iii.	June	13	5	14	12	331	41	20	47	2·1397
412	(141)	— iv.	June	30	21	172	6	104	4	14	31	0·8865
413	326	— v.	Dec.	11	3	170	19	206	42	31	10	1·4277

389. An apparition of *Faye's Comet.*
392. Very faint, say 12th mag., with a tail 15° long.
395. An elliptic orbit; period assigned, 7·07 years.
396. An elliptic orbit; period assigned, 8·53 years.
401. An apparition of *D'Arrest's Comet.*
402. An elliptic orbit.
403. An elliptic orbit; period assigned 6·40 years.
405. An apparition of *Wolf's Comet.*

ϵ	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·99990	+	Millosewich	1888, Aug. 7	Brooks	11 weeks
0·54902	+	Möller	— Aug. 9	Perrotin	4 months
1·0	+	Halm	— Oct. 30	Barnard	4 months or +
1·0	—	Berberich	— Sept. 2	Barnard	2 years or +
0·99952	—	Millosewich	1889, Mar. 31	Barnard	7 months
0·95666	+	Berberich	— June 23	Barnard	6 weeks
0·99650	+	Berberich	— July 19	Davidson	16 weeks
0·47077	+	Bauschinger	— July 6	Brooks	19 weeks
0·67584	+	Hind	— Nov. 16	Swift	2 months ?
1·0	+	Krüger	— Dec. 12	Borelly	3 weeks
1·00037	—	Bidschof	— Mar. 19	Brooks	22½ months
1·0	+	Ebert	— July 18	Coggia	4 weeks
1·0	—	Ristenpart	— Nov. 15	Zona	4 weeks
0·62712	+	Leveau	— Oct. 6	Barnard	6 weeks
0·99915	—	Bobrinskoy	— July 23	Denning	8 weeks
0·47274	+	Tennant	— Nov. 16	Spitaler	12 weeks
1·0	—	Bellamy	1891, Mar. 29	Barnard	4 months
0·55718	+	Thraen	— May 1	Spitaler	5 months
0·84647	+	Backlund	— Aug. 1	Barnard	7 weeks
1·0	+	Berberich	— Oct. 2	Barnard	9 weeks
0·65270	+	Bossert	— Sept. 27	Barnard	16 weeks
0·99861	+	Berberich	1892, Mar. 6	Swift	8 months
1·0	+	Lorentzen	— Mar. 18	Denning	3 weeks
0·40988	+	Boss	— Nov. 6	Holmes	12 weeks
0·72599	+	Von Haerdtl	— Mar. 18	Spitaler	6 months
0·57814	+	Porter	— Oct. 12	Barnard	2 weeks

406. An apparition of *Encke's Comet.*
407. An elliptic orbit; *Barnard's Second Periodical Comet.*
408. An apparition of the *Tempel-Swift Comet.*
409. An elliptic orbit; period assigned, 20,143 years.
411. An elliptic orbit; period assigned, 6·90 years.
412. An apparition of *Winnecke's Comet.*
413. An elliptic orbit; period assigned, 6·22 years.

No.	No.	Year.	PP.			ω		☊		i		q
				d.	h.	°	′	°	′	°	′	
414	327	1892 vi.	Dec.	28	2	252	42	264	29	24	47	0·9757
415	328	1893 i.	Jan.	6	12	85	13	185	38	143	51	1·1951
416	329	— ii.	July	7	7	47	7	337	20	159	57	0·6745
417	(299)	— iii.	July	12	3	315	31	52	27	3	2	0·9891
418	330	— iv.	Sept.	19	8	347	43	174	56	129	48	0·8150
419	331	1894 i.	Feb.	9	11	46	16	84	21	5	31	1·1472
420	332	— ii.	April	13	10	324	12	206	23	86	59	0·9830
421	(254)	— iii.	April	23	6	185	5	121	10	12	44	1·3505
422	(53 ?)	— iv.	Oct.	12	4	296	35	48	48	2	57	1·3920
423	(105)	1895 i.	Feb.	4	18	184	39	334	44	12	54	0·3410
424	333	— ii.	Aug.	20	20	167	47	170	16	2	59	1·2978
425	334	— iii.	Oct.	21	20	298	46	83	5	76	14	0·84303
426	335	— iv.	Dec.	18	8	272	40	320	29	141	37	0·19193
427	336	1896 i.	Jan.	31	18	358	20	208	50	155	44	0·5873
428	(171)	— ii.	March	19	6	201	13	209	53	11	20	1·7404
429	337	— iii.	April	17	16	1	44	178	15	55	34	0·5663
430	338	— iv.	July	10	23	41	3	150	59	88	26	1·1428
431	339	— v.	Oct.	28	2	139	29	192	5	11	32	1·4816
432	(313)	— vi.	Nov.	4	4	343	48	18	4	6	4	1·959
433	340	— vii.	Nov.	24	14	163	53	246	34	13	40	1·1102
434	341	1897 i.	Feb.	8	2	172	18	86	28	146	8	1·0628
435	(195)	— ii.	June	2	19	173	4	146	25	15	43	1·3269
436	342	— iii.	Dec.	8	15	65	53	32	3	69	35	1·3567
437	343	1898 i.	March	17	3	47	19	262	26	72	31	1 0952
438	(141)	— ii.	March	20	12	173	21	100	53	17	0	0·9241

417. An apparition of *Finlay's Comet.*
419. An elliptic orbit; period assigned, 7·419 years.
420. An elliptic orbit; period assigned 1,143 years.
421. An apparition of *Tempel's Second Comet.*
422. An elliptic orbit; period assigned, 5·85 years. Possibly a return of *Di Vico's Comet,* and of the Comet of 1678.
423. An apparition of *Encke's Comet.*
424. An elliptic orbit; period assigned, 7·06 years. Perhaps a return of *Lexell's Comet.*
427. Discovered also by Lamp on February 15.

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
1·0	+	Oppenheim	1892. Aug. 28	Brooks	13 weeks
1·0	—	Porter	— Nov. 19	Brooks	12 weeks
1·0	—	Cerulli	1893, July 8	Rordame	6 weeks
0·71950	+	Schulhof	— May 17	Finlay	15 weeks
1·0	—	Krüger	— Oct. 16	Brooks	7 weeks
0·69839	+	Gast	1894, Mar. 26	Denning	10 weeks
0·99112	+	Peck	— Apr. 1	Gale	5 months
0 55108	+	Schulhof	— May 8	Finlay	5 weeks
0·57157	+	Seares	— Nov. 20	E. Swift	10 weeks
0·84600	+	Backlund	— Oct. 31	Perrotin	4 months
0·64773	+	Berberich	— Aug. 20	Swift	8 weeks
1·0	+	Wassilief	— Nov. 21	Brooks	3 weeks
1·0	—	Lamp	— Nov. 17	Perrine	3 months
1 0	—	Buchholz	1896, Feb. 14	Perrine	5 weeks
0·54902	+	Strömgren	— Sept. 26	Javelle	4 weeks
1·00047	+	Aitken	— Apr. 15	Swift	5 weeks
1·0	+	Peck	— Aug. 31	Sperra	4 weeks
0·65748	+	Hussey	— Sept. 4	Giacobini	9 weeks
0·4694	+	Bauschinger	— June 20	Javelle	15 weeks
0 67929	+	Ristenpart	— Dec. 8	Perrine	3 months ?
1 00093	—	Peck	— Nov. 2	Perrine	6 months
0·62611	+	Leveau	1897, June 28	Perrine	5 weeks
1·0	+	Wessell	— Oct. 16	Perrine	6 weeks
0·98038	+	Curtis	1898, Mar. 20	Perrine	8 months
0·71472	+	Von Haardtl	— Jan. 2	Perrine	

428. An apparition of *Faye's Comet.*
429. A hyperbolic orbit.
430. Orbit nearly perpendicular to the ecliptic.
431. An elliptic orbit ; period assigned, 9.0 years.
432. An apparition of *Brooks's Second Comet.*
433. An elliptic orbit ; period assigned, 6.44 years.
434. A hyperbolic orbit.
435. An apparition of *D'Arrest's Comet.*
437. An elliptic orbit ; period assigned, 417 years.
438. An apparition of *Winnecke's Comet.*

No.	No.	Year.	PP.			ω		☊		i		q
				d.	h.	°	′	°	′	°	′	
439	(105)	1898 iii.	May	24	12	183	59	334	46	12	54	0·3423
440	(290)	— iv.	July	4	13	172	53	206	29	25	12	1·6030
441	344	— v.	July	25	12	313	36	212	12	155	0	1·5013
442	345	— vi.	Aug.	16	7	204	54	259	8	70	1	0·6353
443	346	— vii.	Sept.	14	1	233	15	74	0	69	56	1·7016
444	347	— viii.	Sept.	20	3	4	37	95	51	22	30	2·2850
445	348	— ix.	Oct.	20	13	162	20	34	53	28	51	0·4204
446	349	— x.	Nov.	23	4	123	32	96	18	140	20	0·7560
447	350	1899 i.	April	12	23	8	41	25	0	146	15	0·3265
448	(325)	— ii.	April	28	2	14	4	331	44	20	48	2·1282
449	(111)	— iii.	May	4	5	116	29	269	49	54	29	1·0191
450	(254)	— iv.	July	28	12	185	36	120	57	12	38	1·389
451	351	— v.	Sept.	13	21	10	9	272	16	77	3	1·7830
452	352	1900 i.	April	28	4	23	8	40	7	146	37	1·3459
453	353	— ii.	Aug.	3	4	12	25	328	0	62	31	1·02
454	354	— iii.	Nov.	28	4	171	29	196	32	29	52	0·9342
455	355	1901 i.	April	24	6	203	2	109	38	131	5	0·2448
456	(105)	— ii.	Sept.	15	10	183	59	334	48	12	53	0·3430
457	356	1902 i.	April	24	6	203	1	109	37	131	5	0·2447
458	357	— ii.	June	20	8	301	46	217	31	16	43	0·5838
459	358	— iii.	Nov.	23	19	152	57	49	21	156	21	0·4011
460	359	1903 i.	March	16	0	133	41	2	17	30	55	0·4106
461	360	— ii.	March	23	12	5	43	117	29	43	54	2·7789
462	361	— iii.	March	25	10	184	57	213	8	66	29	0·4994
463	362	— iv.	Aug.	27	15	127	21	293	32	84	59	0·3292
464	(313)	— v.	Dec.	6	10	343	38	18	4	6	4	1·9586
465	363	1904 i.	March	5	18	53	2	275	41	125	6	2 704

439. An apparition of *Encke's Comet.*
440. An apparition of *Wolf's Comet.*
443. A hyperbolic orbit.
445. Discovered independently by Chofardet on September 14.
446. An elliptic orbit; period assigned, 87,000 years!!
447. A hyperbolic orbit.
448. An apparition of *Holmes's Comet.*
449. An apparition of *Tuttle's Comet.*

ε	μ	Calculator.	Date of Discovery.	Discoverer.	Duration of Visibility.
0·84635	+	Iwanow	1898, June 7	Grigg	1 week or more?
0·55534	+	Thraen	— June 16	Hussey	9 months
1·0	—	Hnatek	— June 18	Giacobini	9 weeks
1·0	+	Berberich	— June 14	Perrine	1 week
1·00103	+	Merfield	— June 11	Coddington	15 months
1·0	+	Coddington	— Nov. 14	Chase	8 weeks
1·0	+	Berberich	— Sept. 12	Perrine	2 weeks
0·99974	—	Scharbe	— Oct. 20	Brooks	4 weeks
1·00035	—	Merfield	1899, Mar. 3	Swift	5 months
0·82170	+	Rahts	— Mar. 5	Wolf	17 weeks
0·54211	+	Schulhof	— May 6	Perrine	7 months
0·41133	+	Zwiers	— June 10	Perrine	3 months
1·0	+	Winther	— Sept. 29	Giacobini	9 weeks
1·0	—	Giacobini	1900, Jan. 31	Giacobini	8 months
1·00042	+	Poor	— July 23	Borelly	10 weeks
0·74168	+	Kreutz	— Dec. 20	Giacobini	8 weeks
1·0	—	Merfield	1901, Apr. 12	Many observers	
0·84599	+	Thonberg	— Aug. 5	Wilson	4 weeks
0·99979	—	Merfield	1902, Apr. 14	Brooks	6 weeks
1·0	+	Grigg	— July 22	Grigg	12 days
1·0	—	Strömgren	— Aug. 31	Perrine	7 months
1·0	+	Ebell	1903, Jan. 15	Giacobini	4 months
1·0	+	Ebell	1902, Dec. 2	Giacobini	7 months
1·0	+	Peck	1903, Apr. 16	Grigg	6 weeks
1·0	+	Fayet	— June 11	Borelly	19 weeks
0·46978	+	Neugebauer	— Aug. 20	Aitken	6 months
1·0	—	Yowell	1904, Apr. 16	Brooks	12 months or +

450. An apparition of *Tempel's Second Comet* (1873, ii.).
453. Discovered also by Brooks the same evening as Borelly, but five hours later: a hyperbolic orbit.
454. An elliptic orbit; period assigned, 6·87 years.
456. An apparition of *Encke's Comet.*
461. Perihelion distance unusually large.
462. Elements not very certain.
464. An apparition of *Brooks's Second Comet* (1889, v.).
465. Perihelion distance unusually large.

No.	No.	Year.	PP.			ω		☊		i		q
				d.	h.	°	′	°	′	°	′	
466	364	1904 ii.	Oct.	25	12	35	31	217	35	99	10	1·8450
467	(254)	— iii.	Nov.	10	11	185	44	120	59	12	38	1·3878
468	(105)	1905 i.	Jan.	11	8	184	36	334	27	12	36	0·3386
469	365	— ii.	Jan.	16	17	352	12	76	38	30	33	1·3946
470	366	— iii.	April	4	1	358	13	157	23	40	14	1·1151
471	367	— iv.	Oct.	18	15	158	39	342	18	4	16	3·339
472	368	— v.	Oct.	25	18	132	42	222	56	140	34	0500
473	369	— vi.	Dec.	22	5	89	43	286	22	126	27	·2955
474	370	1906 i.	Jan.	22	8	199	11	92	5	43	39	0·2159
475	371	— ii.	Feb.	20	17	274	46	71	47	84	36	0·7067
476	(325)	— iii.	March	14	4	14	17	331	45	20	48	2·1218
477	372	— iv.	May	2	14	19	31	263	47	8	43	1·6985
478	(299)	— v.	Sept.	8	8	315	48	52	22	3	3	0·9646
479	373	— vi.	Oct.	10	2	200	41	194	19	14	31	1·6305
480	374	— vii.	Nov.	21	8	8	42	84	56	56	33	1·2145
481	375	1907 i.	March	19	6	317	10	97	11	141	39	1·1262
482	376	— ii.	March	27	13	328	47	189	2	109	39	0·9246
483	377	— iii.	May	27	4	34	3	161	5	15	44	1·261
484	378	— iv.	Sept.	3	18	294	47	143	2	9	9	0·506
485	379	— v.	Sept.	13	17	293	27	54	54	119	23	0·9799
486	380	— vi.	Dec.	6	1	39	26	317	7	10	27	3·8415
487	(105)	1908 i.	April	30	4	183	35	334	30	12	37	0·3376
488	(247)	— ii.	Sept.	30	21	334	18	290	18	5	26	1·1535
489	381	— iii.	Dec.	25	21	171	39	103	11	140	11	0·9446
490	382	1909 i.	June	5	7	5	4	305	21	51	54	0·8418
491												

467. An apparition of *Tempel's Second Comet* (1873, ii.).
468. An apparition of *Encke's Comet.*
469. An elliptic orbit; period assigned, 7·20 years.
470. An elliptic orbit; period assigned, 279 years.
471. Perihelion distance the 3rd largest known. Found on a photographic plate taken January 14, 1905, or more than a year before its discovery visually.
476. An apparition of *Holmes's Comet.*
477. An elliptic orbit; period assigned, 6·640 years.